Habitat Restoration Plan for the Lower Tuolumne River Corridor

Prepared for:

The Tuolumne River Technical Advisory Committee

March 2000

Front cover photographs (clockwise from top-left)

- Adult chinook salmon returning to the river to spawn
- A dynamic gravel bar near Basso Bridge at river mile 49.2
- La Grange Dam at river mile 52.2
- Mature valley oak and Fremont cottonwood riparian forest

HABITAT RESTORATION PLAN FOR THE LOWER TUOLUMNE RIVER CORRIDOR

FINAL REPORT

Prepared for:

The Tuolumne River Technical Advisory Committee

With assistance from:

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ACKNOWLEDGMENTS

This Habitat Restoration Plan for the Lower Tuolumne River Corridor has, in actuality, been in the making during the past three decades since the New Don Pedro Project was completed in 1971. During this time, numerous scientists, ranging from resource agency personnel and river restoration specialists to student field technicians, have contributed endless hours of labor gathering information and contributing their knowledge on river and salmon ecology, fluvial and hydrologic processes, insights on site-specific conditions, and management strategies along the 52 mile river corridor. This considerable effort was made in the name of restoring the Tuolumne River, saving the chinook salmon population, and protecting a valued resource that will be passed along to future generations. Our connected legacy lies in the success of our efforts.

We have attempted to synthesize the relevant information that was available to describe the historical and contemporary river conditions into a unified, refined restoration strategy. This culmination would not have been possible without many individuals who contributed directly or indirectly to this report. The members of the Tuolumne River Technical Advisory Committee (TRTAC), many of whom were involved in negotiating the 1995 FERC Settlement Agreement, deserve foremost recognition for their cooperation and shared vision toward the goal of improving the Tuolumne River ecosystem. Of the many technical committees with whom we’ve worked, the TRTAC has been the most collegial, knowledgeable, and professional of them all.

The TRTAC members also contributed to the content of the Restoration Plan by providing several valuable reviews and edits of the draft Restoration Plan. Several local landowners have contributed to this report and restoration process, including the Warner family, Will Streeter, Walt Deardorff, the Sawyer family, Joe Ruddy, the Hall family, Paul Von Konynenburg, and the Zanker family, among others. The City of Modesto and Stanislaus County Regional Planners deserve mention for their efforts to incorporate their vision for the Tuolumne river Regional Park into a long-term vision for the entire community. Carol Vierra, Joe Ruddy, Bill Brown, and Ron Turcott have contributed to making the Gravel Mining Reach restoration project possible.

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PREFACE

The Tuolumne River is one of the most important natural resources of California's Great Central Valley. The largest tributary of the San Joaquin River, the Tuolumne River drains a 1,900 square-mile watershed that includes the northern half of Yosemite National Park. As the Tuolumne River emerges from the Sierra Nevada foothills into the Central Valley, it carries precious agricultural and municipal water supplies to a highly developed and diversified regional economy. Agriculture, ranching, mining, and tourism dominate the region and depend on the river for their sustained livelihoods.

An enormous biological community also depends on the Tuolumne River. Vast Fremont cottonwood and Valley Oak riparian forests once insulated the Tuolumne River banks, extending several miles wide in the lower San Joaquin Valley, and merging into riparian forests of the neighboring Merced, Stanislaus and San Joaquin rivers. These forests provided foraging and breeding habitat for a diverse array of resident and migratory bird and wildlife populations, including tremendous populations of migratory waterfowl. Despite recent declines, the Tuolumne River still supports the largest naturally reproducing population of chinook salmon remaining in the San Joaquin Valley.

The Turlock Irrigation District (TID) and the Modesto Irrigation District (MID), which own and operate the New Don Pedro Dam and Reservoir and La Grange Dam, and provide water and electricity to much of Stanislaus County, have a legal and historic role as stewards of the Lower Tuolumne River. Sharing in this responsibility as stewards of the Tuolumne River's natural resources are regulatory agencies and stakeholders, including several state and federal resource agencies, public utilities, and private organizations. This group includes TID, MID, California Department of Fish and Game (CDFG), US Fish and Wildlife Service (USFWS), the Federal Energy Regulatory Commission (FERC), the National Marine Fisheries Service (NMFS), the City and County of San Francisco (CCSF), San Francisco Bay Area Water Users Association (BAWUA), Friends of the Tuolumne (FOTT), the Tuolumne River Preservation Trust (TRPT), Tuolumne River Expeditions (TRE), and California Sports Fishing Protection Alliance (CSFPA).

The Tuolumne River stakeholders entered into an historical agreement in 1995, following re-evaluation of the original FERC license for the New Don Pedro Project (NDPP). This historic agreement, known as the 1995 FERC Settlement Agreement (Settlement Agreement or FSA) established several important strategies for reversing the decline of fall-run chinook salmon in the lower Tuolumne River: (1) higher minimum instream flow requirements below La Grange Dam, (2) expanded chinook salmon monitoring program, (3) development and implementation of a lower Tuolumne River chinook salmon habitat restoration program, and (4) salmon management and habitat restoration activities coordinated and administered through a *Tuolumne River Technical Advisory Committee* (TRTAC), composed of the stakeholder organizations.

A central directive of the FERC Settlement Agreement was to identify and implement ten priority habitat restoration projects by the year 2005, at which time FERC would evaluate progress toward Settlement Agreement objectives. As part of this process to identify and implement ten priority restoration projects, the TRTAC has commissioned fisheries habitat restoration scientists to develop a "Habitat Restoration Plan for the Lower Tuolumne River Corridor" (Restoration Plan).

The Restoration Plan will be used by the TRTAC to help fulfill its obligations to the FERC under the 1995 Settlement Agreement. The Restoration Plan is a technical resource document intended to aid in identifying areas of potential habitat improvement and provide guidance for restoring or rehabilitating these areas. The Plan is not intended to supercede regulatory agency management obligations and previously developed restoration plans (e.g., CDFG 1990, 1992, CVPIA/AFRP 1995, CALFED ERPP 1999, and CALFED Strategic Plan 1998), but instead is intended to provide additional technical information to the TRTAC for use in making restoration decisions.

Implementation of any specific habitat restoration project will be subject to prior environmental documentation and review as required by state and federal regulations (California Environmental Quality Act; National Environmental Policy Act). Selected projects will be subject to pre-project planning discussions with affected landowners other interested public entities, along with participation from applicable federal, state, and local regulatory agencies. Restoration activities may include the transfer of private lands, mineral rights, water rights, etc., through purchase, conservation easement, or other means. Participation in restoration activities by landowners and other members of the public is entirely voluntary. The TRTAC stakeholders understand that decisions affecting the lower Tuolumne River are influenced by policies relating to land use, water supply and use, water quality, flood control, fish and wildlife, and recreation, and are not governed solely by physical habitat considerations.

The Tuolumne River Technical Advisory Committee

EXECUTIVE SUMMARY

Prior to major human settlement and land development in the Great Central Valley of California, the lower Tuolumne River was a dynamic, meandering alluvial river, with broad floodplains and terraces, large gravel bar deposits, and extensive riparian wetlands and forests harboring a rich diversity of species. An alluvial river has riverbed, banks, and floodplains composed of coarse and fine sediments (sand, gravel, and cobble) that were eroded, transported, and deposited by the forces of running water. A natural river is dynamic, having the ability to frequently move the channelbed and banks, scour coarse sediments and transport them downstream, to be replaced by comparable material transported from upstream. In this way, the morphology or shape of the river channel is maintained in a state of "dynamic quasi-equilibrium" over time. This condition provides the physical foundation of the riverine ecosystem upon which native plant and animal communities depend for their survival. Native flora and fauna *evolved* within this natural riverine environment. Alteration of this physical environment, as has occurred extensively on the Tuolumne River, has adversely impacted the native salmon fishery along with associated plant and animal communities.

The fundamental premise of this Restoration Plan is that a dynamic, healthy river ecosystem can be restored on the Tuolumne River if the fluvial geomorphic and hydrologic processes that create and maintain the physical landscape are restored. River ecosystems are extremely complex; fluvial geomorphic and hydrologic processes sustain an alluvial river's structure and function. Therefore, improving natural processes within the constraints of present-day flow conditions, sediment supply, and land use must be an integral strategy for restoring and managing the Tuolumne River. While advocating this fundamental premise, we acknowledge that restoration actions cannot be expected to return the Tuolumne River to historical conditions that existed prior to modern settlement and intensified land development of the region. Instead, physical processes are intended to be used as *tools* for creating and maintaining habitat, in accordance with other management strategies. Success of this approach is fundamentally dependent on adaptive management techniques to evaluate restoration opportunities, the efficacy of actions and approaches, and then redirect strategies if needed. The Tuolumne River Technical Advisory Committee (TRTAC) will be the focus of this process.

The purpose of each chapter in this Restoration Plan is as follows:

- CHAPTER 1: Provide background information describing the need to develop a technically-based Restoration Plan;
- CHAPTER 2: Integrate salmon ecology and management with contemporary knowledge of fluvial geomorphic and hydrologic processes to develop an ecosystem-based restoration strategy;
- CHAPTER 3: Conduct and present results of fluvial geomorphic and riparian investigations that evaluated contemporary fluvial geomorphic processes, riparian conditions, and potential aggregate sources for restoration purposes;
- CHAPTER 4: Integrate this information to present river-wide and reach-specific restoration goals and strategies, a comprehensive list of all potential restoration sites and actions, and conceptual designs for fourteen high priority restoration projects;
- CHAPTER 5: Develop an Adaptive Environmental Assessment and Management (AEAM) approach that recommends river-wide and site specific monitoring objectives, guides future management, and ensures restoration and maintenance of the fishery resources of the Tuolumne River.

Historical and Contemporary Conditions

<u>Hydrology.</u> The streamflow hydrology of the Tuolumne River has changed from unimpaired conditions due to the cumulative water storage and diversion projects in the watershed. Hydrologic analyses of streamflow records from the USGS gaging station at La Grange (Station 11-289650, immediately downstream of La Grange Dam) illustrates three basic trends in hydrologic alteration: (1) the annual water yield to the lower Tuolumne River below La Grange dam has been progressively reduced by dam regulation and diversion, from an average annual unimpaired yield of 1,906,000 acre feet, to a post New Don Pedro Project (NDPP) regulated annual yield of 772,000 acre-feet, a 60% reduction in flow volume; (2) specific "components" of the annual

hydrograph, including summer and winter baseflows, fall and winter storms, and spring snowmelt runoff have been reduced in all water year types from unimpaired conditions, including reductions in magnitude and variability; (3) the magnitude, duration, and frequency of winter floods have been reduced by regulation from NDPP compared to unimpaired conditions; the mean annual flood (based on annual maximum series) has been reduced from 18,400 cfs to 6,400 cfs; the 1.5-year recurrence event (approximately bankfull discharge) has been reduced from 8,400 cfs to 2,600 cfs; the 10-year recurrence event has been reduced from 36,000 cfs to 9,500 cfs. This reduction in hydrology has, in turn, caused changes to fluvial geomorphic processes, riparian vegetation, riverine habitats, and the biota that uses these riverine habitats.

Chinook Salmon. The fall-run chinook salmon is the predominant anadromous salmonid run on the Tuolumne River. Once thought to have numbered in the hundreds of thousands (including spring-run chinook), chinook salmon have declined to small fractions of their previous numbers. Since 1951, the Tuolumne River salmon population has experienced large fluctuations, ranging from 100 to 45,000 spawners. The lowest San Joaquin Basin escapement of record occurred in 1963 with only 300 spawners in the entire basin. Tuolumne River escapements have plummeted from a high of 41,000 salmon in 1985 to 100 salmon in 1990, 1991, and 1992. Salmon returns in recent years (1997-1999) have rebounded to near ten thousand adults.

Several multi-year research programs conducted by the TID/MID, USFWS, and CDFG to assess chinook salmon population dynamics and habitat conditions on the Tuolumne River identified several "limiting factors" to chinook salmon production and survival. These factors included:

- reduced spawning gravel quantity and quality, egg mortality from redd superimposition, and low egg survival -to-emergence;
- inadequate streamflow during fry and juvenile emigration;
- reduced and degraded fry and juvenile rearing habitat;
- increased in-river predation by non-native fish species;
- increased Bay/Delta and ocean mortality (predation, Delta pumping mortality, sport and commercial harvest);
- elevated in-river and Delta water temperatures.

Many of these factors are related to degradation of habitat within the Tuolumne River corridor, which is in turn related to impaired fluvial geomorphic processes, flow regulation, and physical impacts from land use. The Settlement Agreement reverses some of these factors with improved flows and physical habitat restoration efforts; however, the processes that create and maintain habitat must still be incorporated into restoration efforts.

Riparian vegetation. Riparian corridors are uniquely dominated by winter-deciduous hardwood trees (e.g., cottonwood, willow, valley oak) which can only survive within the particular microclimatic and edaphic (soil moisture) conditions available within the river corridor. In California, the native amphibian, bird, and mammalian species diversity in Central Valley riparian zones represents the highest biodiversity found anywhere in the state (Tietje et at. 1991). Riparian zones support at least 50 amphibian and reptile species, 147 bird species, 55 mammalian species, and 60 native tree and plant species.

The Tuolumne River riparian corridor is presently a small remnant of historical conditions. The Restoration Plan inventoried riparian vegetation within the entire Tuolumne River corridor using the plant series classification system developed by Sawyer and Keeler-Wolf (1995). Of the 29 riparian plant series identified, all native terrestrial vegetation series within the Tuolumne River corridor are classified as "threatened" or "very threatened", with the exception of narrow-leaf willow and white alder. Dramatic losses of these large riparian stands has occurred from cumulative impacts of land uses, including agriculture, urban encroachment, aggregate mining, gold mining, and flow regulation. Riparian vegetation on the lower Tuolumne River is a composite of relic pre-NDPP vegetation on terraces, and post-NDPP vegetation on smaller recently built "floodplains". Pre-NDPP vegetation reflects a larger hydrologic scale. This dramatic reduction in riparian vegetation, and the recognition that riparian zones are biologically rich and thus vital to river ecosystem integrity, have made riparian habitat preservation and restoration high priorities. Cottonwood and valley oak series are particularly important overstory species, providing habitat critical for birds (egrets, herons, osprey, bald eagles, and others). Dense understory habitat provided by willow and herbaceous plants is important for wildlife such as rodents (including the endangered riparian brush rabbit), deer, and their predators.

Fluvial Geomorphology. The lower Tuolumne River corridor is divisible as two distinct geomorphic zones. The sand-bedded zone extends from RM 0.0 to RM 24, and the gravel-bedded zone extends from river mile 24 to 52.2. The corridor can be further subdivided into seven distinct reaches based on present and historical land uses. These historical land uses include:

- placer mining for gold
- dredger mining for gold
- urban growth
- livestock grazing
- agriculture
- streamflow regulation and diversion
- commercial aggregate (gravel) mining

These disturbances have cumulatively degraded the lower Tuolumne River ecosystem by:

- decreasing the floodway capacity,
- reducing or eliminating the low-flow and bankfull channel confinement,
- degrading the channel morphology,
- decreasing the frequency of large floods,
- decreasing the variability of inter-annual and seasonal flows,
- eliminating coarse sediment supply,
- creating large in-channel and off-channel aggregate extraction pits,
- reducing riparian vegetation coverage and structural diversity,
- increasing the distribution and abundance of non-native plant, fish, and wildlife species.

The reduced quality of aquatic habitat is partly responsible for decreased chinook salmon escapement over the years. To begin reversing these impacts and improving river ecosystem quality and chinook salmon populations, a framework is needed to guide restoration. Based on interpreting historic conditions on the Tuolumne River (that approach unimpaired conditions), and documenting natural fluvial geomorphic processes in contemporary alluvial rivers, a set of restoration principles, the "Attributes of Alluvial River Integrity" was developed to help quantify restoration objectives. The Attributes are:

Attribute 1. Spatially complex channel morphology.

No single segment of channelbed provides habitat for all species, but the sum of channel segments provides high-quality habitat for native species. A wide range of structurally complex physical environments supports diverse and productive biological communities;

Attribute 2. Flows and water quality are predictably variable.

Inter-annual and seasonal flow regimes are broadly predictable, but specific flow magnitudes, timing, durations, and frequencies are unpredictable due to runoff patterns produced by storms and droughts. Seasonal water quality characteristics, especially water temperature, turbidity, and suspended sediment concentration, are similar to regional unregulated rivers and fluctuate seasonally. This temporal "predictable unpredictability" is a foundation of river ecosystem integrity;

Attribute 3. Frequently mobilized channelbed surface.

In gravel-bedded reaches, channelbed framework particles of coarse alluvial surfaces are mobilized by the bankfull discharge, which on average occurs every 1-2 years. In sand-bedded reaches, bed particles are in transport much of the year, creating migrating channel-bed "dunes" and shifting sand bars.

Attribute 4. Periodic channelbed scour and fill.

Alternate bars are scoured deeper than their coarse surface layers by floods exceeding 3- to 5-year annual maximum flood recurrences. This scour is typically accompanied by re-deposition, such that net change in channelbed topography following a scouring flood usually is minimal. In gravel-bedded reaches, scour was most likely common in reaches where high flows were confined by valley walls;

Attribute 5. Balanced fine and coarse sediment budgets.

River reaches export fine and coarse sediment at rates approximately equal to sediment inputs. The amount and mode of sediment storage within a given river reach fluctuates, but sustains channel morphology in dynamic quasi-equilibrium when averaged over many years. A balanced coarse sediment budget implies bedload continuity: most particle sizes of the channelbed must be transported through the river reach;

Attribute 6. Periodic channel migration and/or avulsion.

The channel migrates at variable rates and establishes meander wavelengths consistent with regional rivers with similar flow regimes, valley slopes, confinement, sediment supply, and sediment caliber. In gravel-bedded reaches, channel relocation can also occur by avulsion, where the channel moves from one location to another, leaving much of the abandoned channel morphology intact. In sand-bedded reaches, meanders decrease their radius of curvature over time, and are eventually bisected, leaving oxbows;

Attribute 7. A functional floodplain.

On average, floodplains are inundated once annually by high flows equaling or exceeding bankfull stage. Lower terraces are inundated by less frequent floods, with their expected inundation frequencies dependent on norms exhibited by similar, but unregulated river channels. These floods also deposit finer sediment onto the floodplain and low terraces;

Attribute 8. Infrequent channel resetting floods.

Single large floods (e.g., exceeding 10-yr to 20-yr recurrences) cause channel avulsions, rejuvenate mature riparian stands to early-successional stages, form and maintain side channels, and create off-channel wetlands (e.g., oxbows). Resetting floods are as critical for creating and maintaining channel complexity as lesser magnitude floods, but occur less frequently;

Attribute 9. Self-sustaining diverse riparian plant communities.

Based on species life history strategies and inundation patterns, initiation and mortality of natural woody riparian plants culminate in early- and late-successional stand structures and species diversities (canopy and understory) characteristic of self-sustaining riparian communities common to regional unregulated river corridors;

Attribute 10. Naturally-fluctuating groundwater table.

Groundwater tables within the floodway are hydrologically connected to the river, and fluctuate on an inter-annual and seasonal basis with river flows. Groundwater and soil moisture on floodplains, terraces, sloughs, and adjacent wetlands are supported by this hydrologic connectivity.

Supplemental Investigations

The Restoration Plan provides analyses of historical and contemporary hydrologic, fluvial geomorphic, riparian, and chinook salmon habitat conditions to the extent that data were available, incorporating relevant information from published literature and professional experience, and from the extensive investigations on salmon ecology conducted on the Tuolumne River by the TID/MID, USFWS and CDFG. In addition, the Restoration Plan conducted geomorphic and riparian investigations to determine the extent to which specific Attributes are attained under regulated sediment and streamflow conditions, and to provide baseline data for evaluating restoration options. These evaluations included:

- Fluvial geomorphic processes: identify reaches that impede gravel transport, estimate streamflow thresholds for gravel transport, measure gravel and sand transport rates downstream of La Grange Dam, identify fine sediment sources, evaluate the M.J. Ruddy 4-Pumps restoration project, and develop channel design objectives based on these evaluations;
- High flow releases: Consider ways to re-operate flood control releases to achieve fluvial geomorphic thresholds;

- Aggregate source inventory: Locate and estimate volumes of aggregate sources along the Tuolumne and Merced Rivers that are available for restoration purposes;
- Riparian vegetation evaluation: conduct a comprehensive, corridor-wide riparian inventory, and develop relationships between fluvial geomorphic processes and natural riparian regeneration.

Goals and Objectives of the Restoration Plan

The heart of the Restoration Plan is provided in a set of principles and actions that, if fully implemented, would help re-establish fluvial geomorphic functions, processes, and characteristics, within contemporary regulated flow and sediment conditions. This strategy will most effectively promote the recovery and maintenance of a resilient, naturally producing chinook salmon population and the river's natural animal and plant communities. These principles and actions are contained in five progressively more detailed sections in Chapter 4, including: (1) a statement of restoration ***goals and objectives***, including existing programs (CDFG, USFWS/AFRP, and CALFED), the FERC Settlement Agreement goals and objectives, and river-wide restoration goals developed in this Plan, (2) formulation of appropriate ***restoration strategies*** for the gravel-bedded and sand-bedded zones, and for each of the seven reaches of the Tuolumne River, (3) specific ***restoration and preservation approaches*** that are appropriate for different restoration needs, (4) ***identification of restoration sites*** along the entire 52 mile corridor, contained in a comprehensive list with specific information for each site, and finally (5) a set of ***restoration conceptual designs*** for 14 high priority projects, which should be among the first group of projects to be implemented.

The long-term goals for restoring the Tuolumne River, developed in this Restoration Plan, are:

- A continuous river floodway from La Grange Dam to the confluence with the San Joaquin River with capacity that safely conveys at least 15,000 cfs above Dry Creek and 20,000 cfs below Dry Creek;
- A continuous riparian corridor from La Grange Dam to the San Joaquin River confluence, with a width exceeding 500 ft minimum in the gravel-bedded zone to a width up to 2,000 ft near the San Joaquin River;
- A dynamic alluvial channel, maintained by flood hydrographs of variable magnitude and frequency adequate to periodically initiate fluvial geomorphic processes (e.g., mobilize channelbed surface, scour and replenish gravel bars, inundate floodplains, and promote channel migration);
- Variable streamflows, such as during chinook spawning, rearing and emigration, to benefit salmon and other aquatic resources.
- A secure gravel supply to replace gravel transported by the high flow regime, thus maintaining the quantity and quality of alluvial deposits that provide chinook salmon habitat;
- Bedload transport continuity throughout all reaches;
- Chinook salmon habitat created and maintained by natural processes, sustaining a resilient, naturally reproducing chinook salmon population;
- Self-sustaining, dynamic, native woody riparian vegetation;
- Continual revision of the adaptive management program, addressing areas of scientific uncertainty that will improve our understanding of river ecosystem processes and refine future restoration and management;
- Public awareness and involvement in the Tuolumne River restoration effort;
- A clean river. Our perception of a river's intrinsic value is largely based on visual aesthetics. To most people, a clean river is worth caring for, and the public will be more conscious of keeping it clean.

Restoration Approaches and Site Identification

A fundamental component of the Restoration Plan was to identify and describe potential restoration sites along the lower Tuolumne River corridor. Restoration sites were identified through several methods, and assessed during numerous field visits. Vital statistics for each site (including river mile and reach location, area, project type, property ownership, a project description and prescription) were tabulated and entered into the Tuolumne River GIS. This comprehensive effort resulted in 184 potential restoration sites. Going from 184 potential restoration sites to on-the-ground implementation requires a technically valid prioritization procedure, extensive landowner participation and support, planning, project management, and engineering. The Tuolunme River Technical Advisory Committee, districts, regulatory agencies, and consultants provide this infrastructure.

Adaptive Management and Implementation

Ecosystem restoration is by necessity experimental, driven by hypotheses advanced by greater understanding of physical processes and interactive biotic responses. The Restoration Plan recognizes recovery will depend on adaptive management by the Tuolumne River Technical Advisory Committee (TRTAC) to regularly evaluate project successes and failures, and then refocus objectives if needed. The recommended adaptive management approach is similar to the strategy outlined as Adaptive Environmental Assessment and Management (AEAM) (Holling 1978), which stresses explicit integration of scientific, economic and social concerns into efforts addressing resource problems. Objectives for adaptive management should include: (1) define policy and management objectives for satisfying the restoration principles, (2) document the status and trends in chinook salmon population dynamics, continuing with the outlined FERC mandated monitoring plan, and (3) intertwine the first two objectives, is to define restoration endpoints.

These are ambitious goals for any program, but much more so for a program attempting large-scale ecological restoration of a river the size of the Tuolumne River. We must acknowledge the inherent uncertainty of our actions, weigh possible outcomes with considerable caution, then proceed with the best techniques available. There is no solution to this scientific uncertainty. Adding the social, political, and economic uncertainties makes river restoration more daunting. But this daunting task does not justify inaction, and the stakeholders involved in the implementation of this Restoration Plan must be willing to accept success with periodic setbacks, substantial amounts of time and money, and the risks involved in decision making.

Copies of this report, or a 16 page *Summary of the Habitat Restoration Plan for the Lower Tuolumne River Corridor* may be obtained from:

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1 INTRODUCTION

1.1 GEOGRAPHIC SETTING

The Tuolumne River is located in the Central Valley of California and is the largest tributary of the San Joaquin River (Figure 1-1). The Tuolumne River originates near 11,000 ft elevation in the Sierra Nevada range, and flows southwesterly between the Merced River watershed to the south and the Stanislaus River watershed to the north, draining 1,900 square miles of west-sloping mountains. It joins the San Joaquin River at RM 83.0, approximately ten miles west of the City of Modesto. Runoff from the Tuolumne River is typified by late spring and early summer snowmelt, typical of other rivers originating in the Sierra Nevada mountains. Annual water yield from the Tuolumne River averaged 1,906,000 acre-feet (af) from 1896 to 1999.

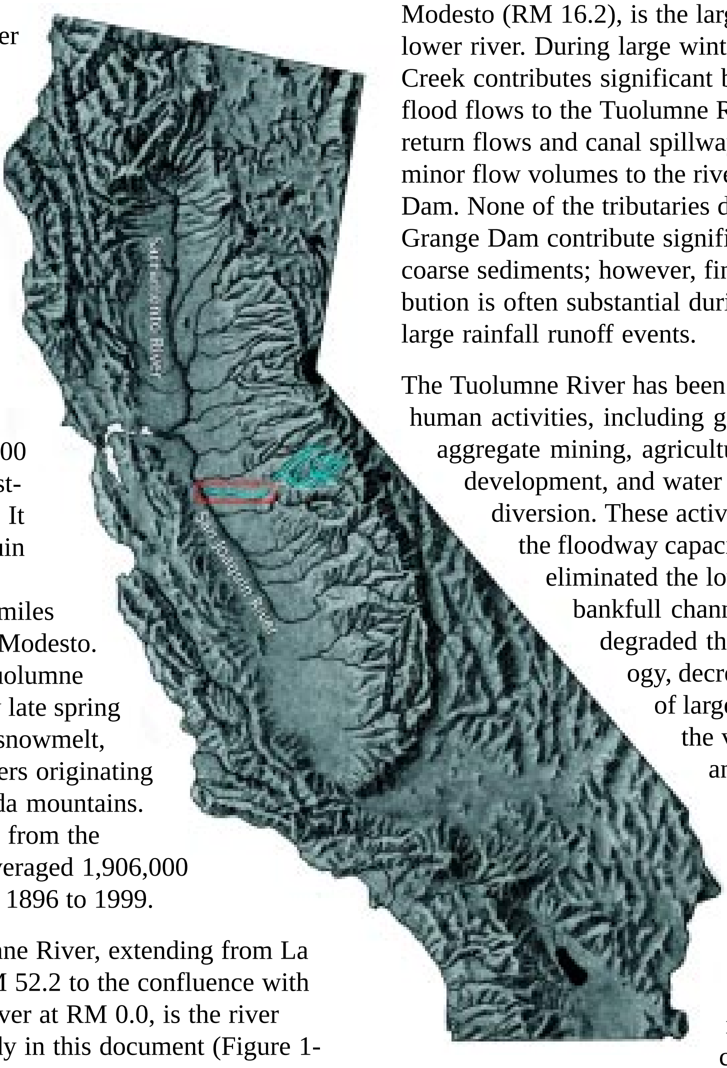


Figure 1-1. Location of the Tuolumne River, Stanislaus County, California.

The Lower Tuolumne River, extending from La Grange Dam at RM 52.2 to the confluence with the San Joaquin River at RM 0.0, is the river segment under study in this document (Figure 1-2). The Lower Tuolumne River (henceforth referred to simply as the Tuolumne River) is primarily alluvial, with bed and banks composed of sand, gravel, and cobble, with occasional exposed bedrock in areas where the steep bluffs of the valley wall confine the channel. Along its longitudinal gradient the river traverses a variety of geomorphic and land use zones, including gravel and sand-bedded zones, the cities of La Grange, Waterford, and Modesto, agricultural areas (row crops and orchards), cattle grazing, and aggregate mining. A narrow band of riparian hardwood forest borders the river channel. La Grange Dam is the lowest in elevation of several dams constructed in the watershed. La Grange Dam is located at the base of the Sierra Nevada foothills, downstream of most major tributaries. Dry Creek, which enters the Tuolumne River in Modesto (RM 16.2), is the largest tributary in the lower river. During large winter rainstorms, Dry Creek contributes significant but short duration flood flows to the Tuolumne River. Agricultural return flows and canal spillways also contribute minor flow volumes to the river below La Grange Dam. None of the tributaries downstream of La Grange Dam contribute significant volumes of coarse sediments; however, fine sediment contribution is often substantial during moderate and large rainfall runoff events.

The Tuolumne River has been impacted by human activities, including gold dredging, aggregate mining, agricultural and urban development, and water storage and diversion. These activities have decreased the floodway capacity, reduced or eliminated the low-flow and bankfull channel confinement, degraded the channel morphology, decreased the frequency of large floods, decreased the variability of inter-annual and seasonal flows, eliminated coarse sediment supply, created large in-channel and off-channel aggregate extraction pits, reduced riparian vegetation coverage and structural diversity, and increased the distribution and abundance of non-native plant, fish, and wildlife species. The cumulative effects of these changes has reduced the quantity and quality of instream habitat for the fall-run chinook salmon (*Oncorhynchus tshawytscha*), made the salmon population unstable, limited native riparian regeneration, and diminished the quantity and quality of terrestrial habitat. In short, the Tuolumne River corridor ecosystem is heavily degraded.

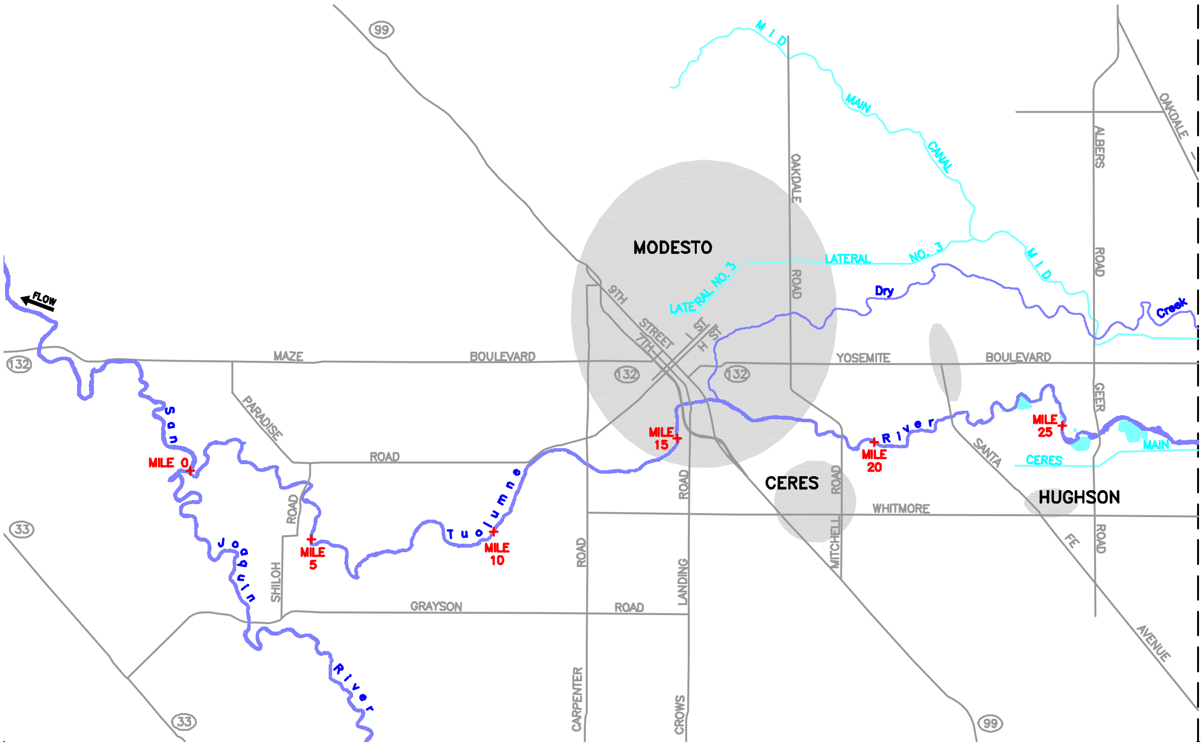


Figure 1-2. Tuolumne River downstream of the New Don Pedro Project (NDPP), showing urban areas, tributaries, TID/ MID regulation facilities, and major roads.

1.2 PRECURSORS TO THIS RESTORATION PLAN

The Tuolumne River has an extensive history of flow regulation and diversion by the Turlock Irrigation District (TID), Modesto Irrigation District (MID), and the City and County of San Francisco (CCSF). The City and County of San Francisco manages three reservoirs on the upper Tuolumne River (Figure 1-3): Hetch-Hetchy Reservoir on the upper mainstem Tuolumne River (363,000 af), Lake Eleanor on Eleanor Creek (27,000 af), and Lake Lloyd on Cherry Creek (268,000 af) for a combined storage capacity of 658,000 af.

The Districts (TID/MID) have jointly operated water storage and diversion facilities on the Tuolumne River near La Grange for over a century (Johnston 1997). The first major facility, La Grange Dam, was constructed in 1893 and continues to serve as the diversion point for the TID and MID main canals. Additional storage needs on the river resulted in construction of the original Don Pedro Dam in 1923 (with a storage capacity of 290,000 af), which was replaced by the New Don Pedro Dam in 1970. The New Don Pedro Project (NDPP) is the largest mainstem storage facility on the Tuolumne River, with a capacity of 2,030,000 acre-feet. Construction of

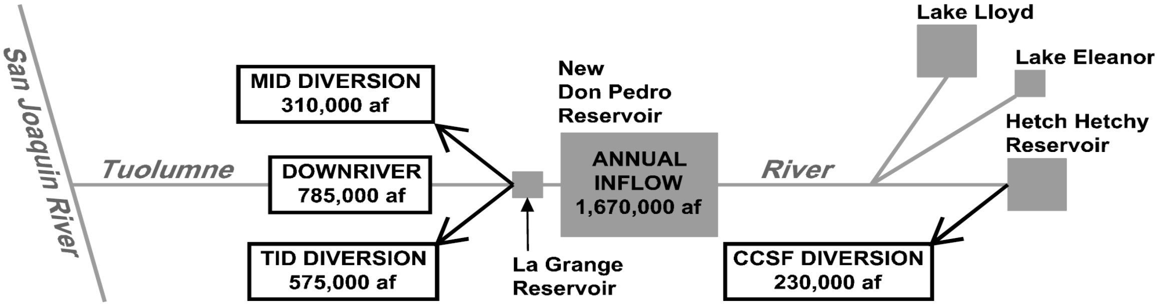
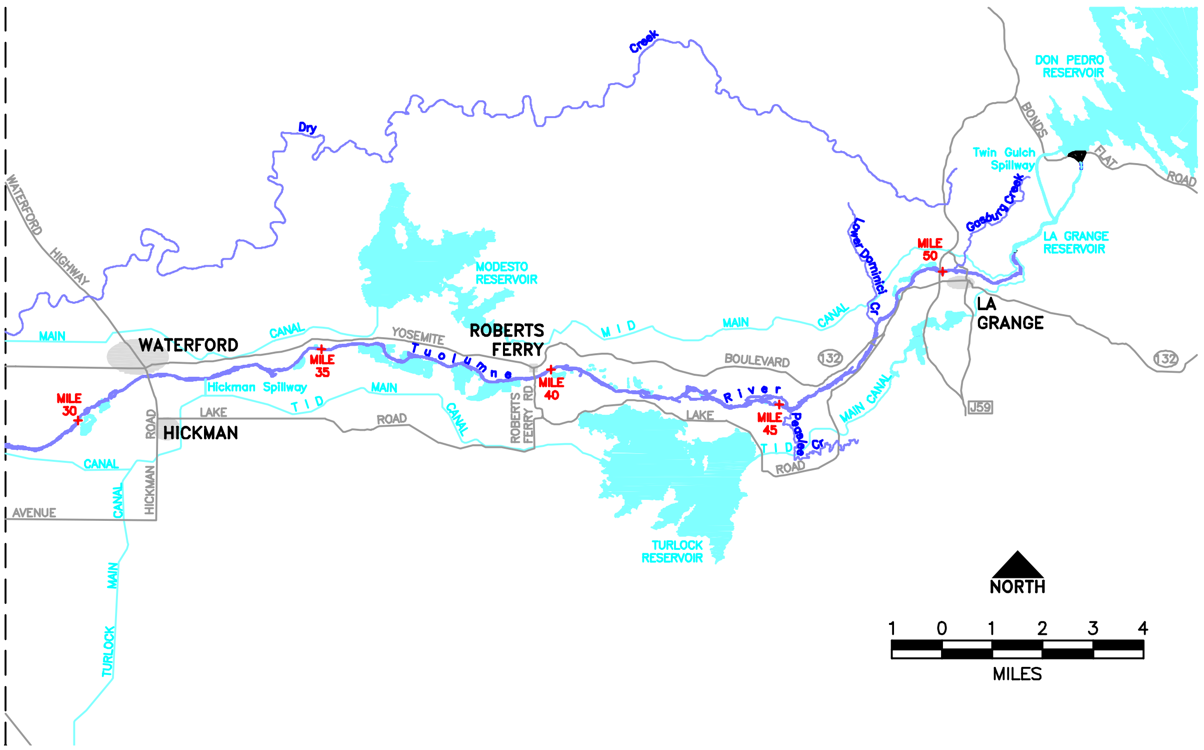


Figure 1-3. Major streamflow diversion structures and volumes of water diverted from the Tuolumne River basin (water volumes are 1984-1998 averages).



NDPP was a joint project of TID, MID, CCSF, and the Army Corp or Engineers (ACOE). The New Don Pedro Project diverts an average of nearly 900,000 af annually, delivering 575,000 af to TID customers, and 310,000 af to MID customers. An additional 230,000 af are diverted from the upper watershed by CCSF for delivery of municipal water supplies to the San Francisco Bay metropolitan area (Figure 1-3).

The Federal Power Commission (later to become the Federal Energy Regulatory Commission [FERC]) issued a license for the NDPP in 1964, which required the Districts, in cooperation with federal and state resource agencies, to conduct studies on the Tuolumne River “aimed at assuring continuation and maintenance of the salmon fishery in the most economical and feasible manner” (Article 39). Studies were conducted cooperatively by the Districts, U.S. Fish and Wildlife Service (USFWS), and California Department of Fish and Game (CDFG) under a 1971 study plan, which was subsequently updated in 1986. These studies described the salmon ecology and provided management recommendations for the Tuolumne River, and are summarized in a series of reports by EA Engineering, Science and Technology (EA 1992; 1997). The Tuolumne River is one of the most intensively studied and documented tributary streams in the Sacramento/San Joaquin River system, and this Restoration Plan attempts to integrate this knowledge with additional analyses and recommendations needed to improve and sustain the salmon population.

In 1992, FERC began proceedings in response to Article 37 of the original NDPP license, which required re-evaluation of minimum flow releases after the first 20 years of project operation. The resulting 1995 FERC Settlement Agreement (Settlement Agreement or FSA) was entered into among stakeholder groups including the FERC (Commission), TID and MID (Districts), CA Department of Fish and Game (CDFG), US Fish and Wildlife Service (USFWS), the City and County of San Francisco (CCSF), San Francisco Bay Area Water Users Association (BAWUA), Friends of the Tuolumne (FOTT), the Tuolumne River Preservation Trust (TRPT), Tuolumne River Expeditions (TRE), and CA Sports Fishing Protection Alliance (CSFPA). The Commission adopted a FERC Order in 1996 amending the FERC license, which subsequently increased minimum

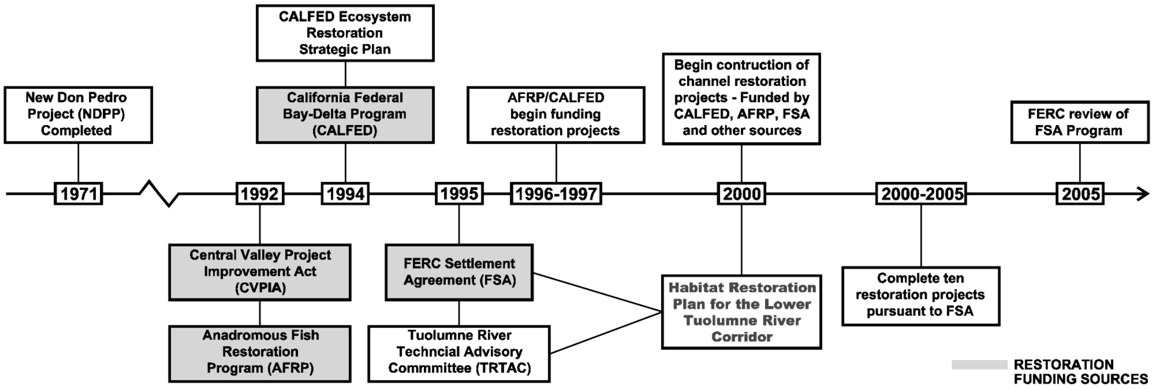


Figure 1-4. Timeline of specific actions required by the FERC Settlement Agreement.

instream flow requirements. The FERC Order required additional reporting on non-flow mitigative measures and an expanded monitoring program.

The 1995 Settlement Agreement outlined a general strategy for restoring the declining fall-run chinook salmon fishery (Sections 8-13 of the FSA), and appointed the Tuolumne River Technical Advisory Committee (TRTAC) to oversee implementation of the restoration measures. The TRTAC then chose to prepare a restoration plan to guide planning and implementation of a comprehensive recovery program. The TRTAC in March 1996 approved a pilot geomorphic and salmonid habitat restoration assessment of the lower Tuolumne River downstream of La Grange Dam (McBain and Trush 1996). This pilot assessment led to full-scale development of an integrated, long-term restoration plan for the lower Tuolumne River mainstem. This restoration plan would more thoroughly evaluate general biological and geomorphic watershed processes affecting river ecosystem health and fall-run chinook salmon habitat conditions, gauge the river's restoration potential within present socioeconomic constraints, and guide the design and prioritization of river-wide restoration projects. Additional tasks for the restoration plan included:

- A review of recent biological studies to evaluate factors potentially limiting chinook salmon productivity;
- Fluvial geomorphic and hydrologic investigations to document physical processes most important to river ecosystem restoration in the Lower Tuolumne River;
- Riparian investigations to document historic conditions and contemporary processes that promote natural regeneration of riparian vegetation;
- Evaluation of coarse and fine sediment budgets, including an assessment of tributary and agricultural runoff inputs of fine sediment (silt and sand), and identification of reaches potentially restricting coarse sediment (bedload) transport, and strategies for restoring coarse sediment equilibrium;
- Inventory of all aggregate sources potentially available for use in future restoration projects on the Tuolumne River, along with evaluation of costs and recommendation of strategies for utilizing materials;
- Evaluation of opportunities for re-operation of flood control releases for fluvial geomorphic processes.

This ***Habitat Restoration Plan for the Lower Tuolumne River Corridor (Restoration Plan)*** is the result of efforts by the TRTAC to develop an integrated, long-term plan, pursuant to the direction in the FERC Settlement Agreement, that will improve naturally occurring salmon populations, improve riparian habitat, and improve physical processes that create and maintain river form and function. The timeline for specific actions required by the FERC Settlement Agreement, as well as other programs related to Tuolumne River habitat restoration activities are outlined in Figure 1-4.

1.3 CLARIFICATION OF TERMINOLOGY

1.3.1. Restoration versus Rehabilitation

The term “restoration” often implies a return to a preferable or pristine condition that existed historically. Unfortunately, barring removal of the dams, cessation of agricultural and mining activities within the valley, elimination of water diversion and other large-scale changes, returning to a pre-settlement Tuolumne River corridor is impossible. “Rehabilitation” more realistically describes our task outlined in this Restoration Plan, which is to improve conditions within the Tuolumne River corridor to the fullest extent possible given fluvial geomorphic, hydrologic, and societal constraints, with the understanding that a complete return to pre-degraded conditions and salmon population levels is not feasible. Figure 1-3 illustrates these concepts. We will continue, however, to use the more familiar term “restoration” throughout. The reader must keep in mind that what is intended is “rehabilitation” to help achieve the goals of the Settlement Agreement.

Defining the restoration needs of the Tuolumne River must be based on a sound foundation of information and understanding that will lead to the greatest chance for improving the river corridor. A restoration plan must also have a foundation in river ecology (Stanford et al. 1996).

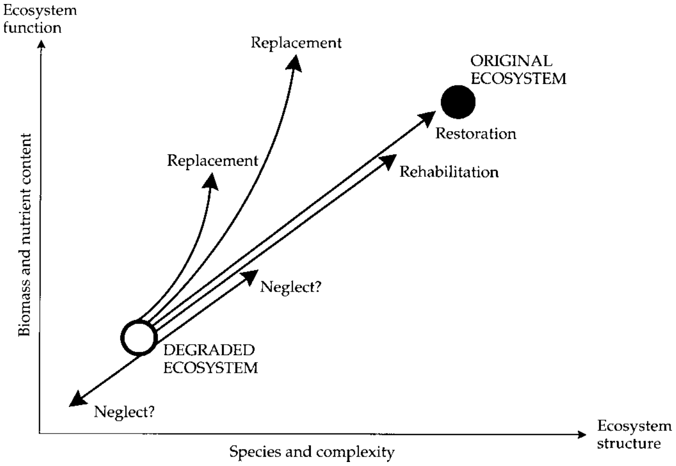


Figure 1-5. Different states of ecosystem recovery based on changes in ecosystem structure and function (modified from Bradshaw, 1984). Note that restoration is near or at original ecosystem structure and complexity. Rehabilitation improves ecosystem structure and complexity, but not to original (historical) levels.

This Restoration Plan incorporates both foundations. Therefore, while chinook salmon are a primary target species, the health and integrity of the ecosystem are given equal priority.

1.3.2. Historical salmonid populations

The Tuolumne River historically supported at least three major runs of anadromous salmonids (sea-going runs): fall-run and spring-run chinook salmon (*Oncorhynchus tshawytscha*), and steelhead trout (*Oncorhynchus Mykiss*). These runs differed in both timing of major life-history stages such as upstream migration, spawning, duration of residence in freshwater, and emigration to the Pacific Ocean, as well as their adaptations to instream habitat. The fall-run salmon historically spawned during fall and early winter months in the mainstem reaches of Central Valley rivers below the foothills, up to approximately 1,000 ft in elevation. In contrast, the spring-run salmon ascended higher into accessible tributaries above the foothills, and depended on cold-water holding habitat during warm summer months, before spawning during fall and early winter months (Healey 1991, Yoshiyama et al. 1998). Steelhead trout also ascended higher into Central Valley tributaries to spawn during late-fall and winter months. Because of these general differences in life history timing and habitat requirements, each run responded uniquely to major land use developments that have occurred during the past century. The spring-run chinook population, believed to have been the most abundant salmon in the San Joaquin River basin, is now extinct, blocked from its former over-summering and spawning habitat by dams. The steelhead may still persist in relatively small numbers, but debate over its historical distribution and less emphasis in its commercial value has shifted the primary focus away from restoring a viable steelhead run. Only the fall-run chinook salmon run has persisted in appreciable numbers during the last few decades, and now retains the distinct status in the San Joaquin River basin and the Tuolumne River as a potentially viable commercial and recreational fishery worthy of significant and costly basin-wide restoration efforts.

The primary fishery focus of this Restoration Plan is therefore the fall-run chinook salmon population, while secondarily acknowledging the historical abundance and importance of other native salmonid species. Henceforth, references to chinook salmon or salmon are specifically to the fall-run population.

1.3.3. Ecosystem-based approach to restoration

This Restoration Plan parallels several ongoing restoration programs targeting California's inland and estuarine water resources. The USFWS Anadromous Fish Restoration Program (AFRP) responded to federal legislation (CVPIA 1992) with the explicit goal of doubling natural production of anadromous fish in Central Valley streams. The CALFED organization is a consortium of federal and state resource agencies mandated by the Bay-Delta Accord with broad objectives of restoring the San Francisco Bay-Delta resources, Sacramento/San Joaquin Rivers, and their tributary streams. The San Joaquin River Management Program was developed by the California Department of Water Resources (DWR) and the US Bureau of Reclamation (USBR) to address problems in the San Joaquin River and its tributary streams. The CDFG "Central Valley Salmon and Steelhead Restoration and Enhancement Plan" (CDFG 1990) outlines CDFG's restoration and enhancement goals for salmon and steelhead resources of the Sacramento and San Joaquin river systems. Finally, the CDFG "Restoring Central Valley Streams: A Plan For Action" (CDFG 1993) was developed to assess present conditions and needs of Central Valley anadromous fish habitat and associated wetlands, then set priorities for taking action to restore and protect California's aquatic ecosystems.

Cumulatively, these diverse interests, plans, and efforts reinforce the need for a comprehensive strategy, reached by consensus among the stakeholder groups comprising the TRTAC, for rehabilitating the Tuolumne River corridor. On many rivers, past management and restoration activities focused primarily on a single species or commercially valued species rather than ecological/physical processes, and success has been limited. Management efforts to improve biodiversity and productivity have also largely failed (Stanford et al. 1996). ***Our approach to rehabilitate the Tuolumne River corridor centers upon restoring hydrologic and fluvial geomorphic processes that are responsible for creating and maintaining river form and function. This, in turn, provides the physical habitat needed to support native aquatic and terrestrial communities.*** We hypothesize that restoring the foundation of the Tuolumne River ecosystem (the physical habitat) will improve salmon habitat and thus the fall-run salmon population. In this respect, we therefore consider this approach "ecosystem restoration", while acknowledging that this restoration approach does not explicitly address every aspect of the ecosystem.

Thus, the Restoration Plan is based on the hydrologic and fluvial geomorphic processes[1] that form and maintain habitat conditions, and therefore control the life histories and distribution of native aquatic and terrestrial communities. Understanding the fundamental ecological processes helps identify ways in which human activities have influenced those processes, and then understand the collateral responses of the life histories of the biota. However, recognizing that chinook salmon are a commercially and socially valued species suggests that our approach unite the best features of single-species management (for chinook salmon), ecosystem restoration and management (to include ecological processes and human influences), and adaptive management (to address uncertainty in management actions). This combined approach offers the opportunity to target chinook salmon restoration goals of the FSA, CDFG, AFRP, and CALFED, and concurrently pursue broader objectives of rehabilitating self-sustaining ecological processes on the Tuolumne River.

This Restoration Plan thus focuses on large scale physical processes, past and present land use activities, and streamflow regulation, in addition to individual species, granting that the primary focus on chinook salmon is socially and economically important. In this strategy, ecological processes are intended as tools to maintain those species and communities more universally valued (Simberloff 1998). This strategy is consistent with the focus and direction of the primary principles

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[1] Henceforth, the term 'fluvial geomorphic processes' will be referred to more simply as 'fluvial processes'.

articulated in the Settlement Agreement. Additionally, the needs of individual species are fundamentally linked to ecosystem processes. Many physical elements proposed for rehabilitation are the same habitat features that potentially limit salmon production. This combined approach allows flexibility in responding to short-term needs of salmon production while simultaneously promoting a long-term vision for a healthy ecological community.

As an example, the Restoration Plan provides the rationale and guidelines for coarse sediment management (spawning gravel introduction) to provide improved salmon spawning conditions (short-term needs), and concurrently recreate conditions which will promote channelbed scour and redeposition, and channel confinement (long-term vision) in presently degraded river reaches.

1.4. SCOPE OF THE RESTORATION PLAN

1.4.1. Corridor versus watershed boundaries

Restoration plans typically delineate geographic limits and target specific species and/or specific habitats. Contemporary watershed analyses use natural watershed boundaries as the geographic limits, rather than using arbitrary boundaries such as county or state lines. These plans also incorporate numerous species that are found within the watershed boundaries. This report does not adhere to the format and breadth of a standard watershed analysis, primarily because the upper Tuolumne River watershed above NDPP is ecologically and geographically isolated from the lower Tuolumne River corridor. Instead, this Restoration Plan is limited geographically to the 52.2 mile lower Tuolumne River floodway below NDPP, including the river channel, adjacent floodplains, and the bluffs which confine the upper reaches. In the lower valley, geographic limits are less distinct, but the floodway should include an appropriate corridor width to contain large floods and mature riparian stands.

Though originally conceived as a watershed analysis, our approach should be considered a river corridor analysis and restoration plan. We are not attempting to separate the river from its watershed; however, often the first hurdle for a proposed restoration project is to limit the project's scope to maintain its effectiveness. The Tuolumne River downstream of La Grange Dam is both a logical and practical division because the NDPP effectively isolates the upper watershed from the lower watershed. An important objective is to determine if a successful salmonid habitat and river ecosystem restoration strategy can effectively occur at the scale of the river corridor below the NDPP. If not, how far and how much of the surrounding watershed should be included. Acknowledging that the NDPP eliminates sediment supply from the upper watershed, blocks anadromous fish access to the upper watershed, and effectively dictates hydrologic conditions downstream, suggests that longitudinal boundaries of this Restoration Plan should extend along the Tuolumne River corridor from La Grange Dam (RM 52.2) downstream to the San Joaquin River confluence (RM 0.0).

Alluvial rivers such as the Tuolumne River are dynamic, and their spatial dimensions vary considerably. A river channel cannot function as an ecosystem independent of the floodplains and historic terraces that are formed and maintained by fluvial processes. The Tuolumne River corridor must include a floodway that, in many locations, requires much greater capacity than now exists for the river to predictably and beneficially function at high flows. Increasing floodway capacity will also improve flood control management and buffer adjacent lands from the river channel. Sequences of historical photos show that the corridor width has been progressively reduced by land use. This Restoration Plan must therefore incorporate strategies for maintaining and increasing the corridor width, and maintain a restored floodway as a primary component of the ecosystem.

1.4.2. Focus on natural chinook salmon production

Within the framework of this Restoration Plan, the explicit connection of ecosystem rehabilitation efforts to chinook salmon production is a key feature. Several programs, including the FSA, AFRP and CALFED expressly mandate restoring and managing for *natural* chinook production, in contrast to artificial production or supplementation as the primary restoration strategy. The FERC Settlement Agreement, for example, states that the recovery strategy for chinook salmon should attempt to "increase naturally occurring salmon populations" using measures that include "increased flows, habitat rehabilitation and improvement, and measures to improve smolt survival." The USFWS AFRP established a production target (harvest and escapement) of 38,000 fall-run chinook salmon as a multi-year average for the Tuolumne River. The AFRP also specifies natural salmon production, defined by the AFRP as "fish produced to adulthood without direct human intervention in the spawning, rearing, or migration processes". The goal of this Restoration Plan in relation to salmon production, therefore, is in accordance with natural production goals mandated by the FERC Settlement Agreement and the Anadromous Fish Restoration Program.

1.5. OBJECTIVES

Objectives of this Restoration Plan were developed during an initial scoping document (McBain and Trush 1996), and have been refined since. Objectives include:

1. *Develop hypotheses to relate historical fluvial processes, channel morphology, and riparian vegetation to the ecological health and integrity of the Tuolumne River. Relate attributes of ecosystem integrity to salmonid physiology and life history strategies, and develop restoration goals based on these inter-relationships.*
2. *Evaluate opportunities for restoring and increasing intra-annual flow variability, such as during chinook spawning, rearing and emigration, to benefit salmon and other aquatic resources.*
3. *Evaluate the coarse sediment budget, identifying sediment supply sources and bedload "traps" that impede coarse sediment routing through the river.*
4. *Identify fine sediment sources that negatively impact chinook habitat, and develop remedial strategies.*
5. *Identify opportunities for achieving fluvial geomorphic thresholds via flow release prescriptions for NDPP, coarse sediment introduction, and channel reconstruction.*
6. *Inventory and classify existing riparian vegetation to establish baseline conditions, evaluate factors that limit natural riparian vegetation recruitment, and identify potential riparian restoration sites.*
7. *Identify, prioritize, and develop proposals for channel reconstruction projects.*
8. *Develop a restoration vision for geomorphically distinct reaches of the Tuolumne River, and river-wide.*
9. *Integrate site specific and river-wide monitoring plans to evaluate future restoration efforts, which can be easily used for adaptive management by the TRTAC.*

A successfully implemented river corridor restoration plan must contain the following components:

- A science-based understanding of the river corridor and the biological communities within it;
- Identification of opportunities and constraints to restoration, including water supply, land ownership, sediment supply, and development along the river;
- A technical stakeholder group to evaluate and implement restoration activities;
- Support of the Restoration Plan by the local community.

The first two components are largely in place. The Tuolumne River Technical Advisory Committee has assumed responsibility for the third component, and have conducted quarterly meetings since 1996. The final important step is to share the Tuolumne River restoration vision with the local community, solicit input from the community, and maintain their involvement in future activities. Occasionally restoration projects have been halted by lack of consensus from even a small segment of the local community. To avoid this situation, the TRTAC has begun (and will continue) the process of "community outreach", by hosting public meetings and workshops to present the Restoration Plan and specific restoration projects, and encourage continued community involvement.

To present the goals and objectives of this Restoration Plan, the remainder of the document is structured in the following way:

Chapter 2 describes the historical and contemporary hydrologic and fluvial processes, the biological and physical processes that perpetuate riparian vegetation patterns (i.e., the interaction with hydrologic and fluvial processes), and chinook salmon adaptations to historical hydrological and physical habitat conditions, and the potential constraints that alterations of those conditions may impose on the salmon.

Chapter 3 describes the technical fluvial geomorphic, hydrologic, and riparian evaluations that were conducted as part of development of the Restoration Plan to supplement the already existing knowledge of chinook salmon life history and ecology.

Chapter 4 presents the restoration vision, restoration strategies for specific river reaches and river-wide, and various restoration approaches available for carrying out the vision and strategies. This chapter also presents a list of restoration sites, and conceptual designs developed for specific projects.

Chapter 5 concludes with strategies for implementing an adaptive management and monitoring program, including both river-wide and restoration project-specific monitoring protocols.

Finally, two appendices contain streamflow hydrographs for the lower Tuolumne River, and riparian vegetation inventory and specie list. A CD Rom is also provided that contains a PDF file of this report, data collected as part of this report, and riparian inventory maps.

2. LINKING PHYSICAL PROCESSES AND SALMON LIFE HISTORY

In the Central Valley, the fall-run chinook salmon is a high priority species demanding considerable energy and money to rebuild and maintain healthy populations. Numerous restoration and management approaches have been applied on the Tuolumne River, such as instream flow (IFIM) and temperature studies, microhabitat restoration (e.g., riffle reconstruction), each with varying degrees of success (Kondolf, et al. 1996). However, most approaches have not been integrative, nor have they attempted to incorporate fluvial and hydrologic processes to restore habitat. Chinook salmon life history adaptations to natural riverine processes are also frequently overlooked in restoration strategies. Recognizing that the different seasonal runs, and perhaps some individual populations of chinook salmon in the Central Valley evolved in response to particular environmental conditions, and that human activities have radically changed those conditions, helps explain how salmon populations have declined so dramatically. This recognition also provides a logical point of departure for developing a restoration strategy.

The TRTAC, other funding entities, and regulatory agencies have the authority and the extraordinary opportunity to dramatically improve conditions in the Tuolumne River. Collateral efforts are underway to address ecological and management problems in the Sacramento - San Joaquin Bay/Delta system and associated watersheds, with goals to improve ecological conditions for priority species such as the fall-run chinook salmon. Ocean harvest regulations have also become much more restrictive in response to declining salmon populations and increasing public pressure. These efforts clearly reflect changing societal values toward maintaining biological diversity in the face of increasing development and use of natural resources. A primary objective of the restoration strategy should be to restore ecological health to the Tuolumne River so that it is not *the* factor limiting natural salmon production.

This chapter examines information on salmon ecology and management derived from previous studies, and describes contemporary knowledge of fluvial (and riparian) processes that create and maintain river ecosystem integrity. Our goal is to integrate historical and contemporary fluvial geomorphic and ecological information with management objectives, acknowledging societal constraints, to provide a technical foundation and planning strategy for restoring the Tuolumne River corridor.

Integration first requires a demonstrated understanding of the physical processes that underpin ecological integrity and provide salmon habitat. We describe how salmon adapted to historical hydrologic and fluvial processes prior to large scale human impact to the corridor. "Conditions" refers to the form of the river corridor and the physical processes that created that form. Our understanding of historical conditions will then suggest hypotheses of how salmon and other aquatic and riparian species depended on those conditions, which can then be used to support hypotheses about specific restoration strategies.

Defining historical conditions is problematic because nearly all quantitative and qualitative descriptions of the Tuolumne River occurred during or after major episodes of human impact. Pristine river conditions were never documented. "Historical" therefore refers to the least disturbed conditions for which information exists and infers what was natural based on contemporary knowledge of alluvial river systems. In the following sections we describe historical and present day hydrology, fluvial geomorphology, and the biological resources within the corridor, and describe how these components interacted to define a healthy river ecosystem.

2.1. HYDROLOGY

2.1.1. The unimpaired flow regime

The natural or "unimpaired" flow regime historically provided large variation in the magnitude, timing, duration, and frequency of streamflows, both inter-annually and seasonally. Variability in streamflows was essential in sustaining ecosystem *integrity* (long-term maintenance of biodiversity and productivity) and *resiliency* (capacity to endure natural and human disturbances) (Stanford, et al. 1996). Restoring the natural flow variability of a river is now recognized as a fundamentally sound approach to initiating river ecosystem restoration (Poff, et al. 1997). River restoration strategies based on restoring flow variability have typically been underutilized in the past, or difficult to implement because of the inherent economic value of water.

We begin by presenting key components of the natural flow regime, using streamflow data prior to initiation of major storage and diversion systems, in addition to "computed natural flows", which are approximated streamflows that would occur in the absence of storage and diversion. Computed natural flows are calculated from measured inflows into Don Pedro Reservoir and diversions from upper-basin reservoirs. Pre-diversion streamflow data and computed natural flows are combined to generate the unimpaired flow record. Long-term daily streamflow records provide statistical documentation of the annual flow regime. The U.S. Geological Survey (USGS) station at La Grange (#11-289650) best documents flow conditions in the upper 28-mile gravel-bedded section of the Tuolumne River, which contains nearly all the chinook spawning and rearing habitat. Additionally, this gage provides streamflow data used by the Districts and CCSF to determine annual water yield. Computed unimpaired streamflows at La Grange and streamflows measured at La Grange provide the following data:

- 102 years of unimpaired annual water yield estimates, in acre-feet (WY1897 to 1998);
- 82 years of unimpaired daily average streamflows, in cfs (WY1918 to 1999);
- 29 years of post-NDPP daily average streamflows, in cfs (WY1971 to 1999);
- 73 years of pre-NDPP annual instantaneous maximum flood flow data, in cfs (WY1897 to 1970);
- 29 years of post-NDPP annual instantaneous maximum flood flow data, in cfs (WY1971 to 1999).

Our hydrologic analysis focused on (1) characterizing inter-annual and seasonal variations in magnitude, timing, duration, and frequency of daily average discharge at La Grange, (2) an analysis of annual water yield, and (3) a flood frequency analysis. The unimpaired flow regime in the Tuolumne River prior to construction of New Don Pedro Dam serves as a baseline for comparing the post-NDPP regulated flow regime. These analyses are then linked to chinook life history, riparian life history, and potential impacts from regulation.

2.1.1.1. Annual hydrograph

Daily average stream flows were plotted as annual hydrographs at La Grange, for WY1918 to 1999 (unimpaired) and WY1971 to 1997 (post-

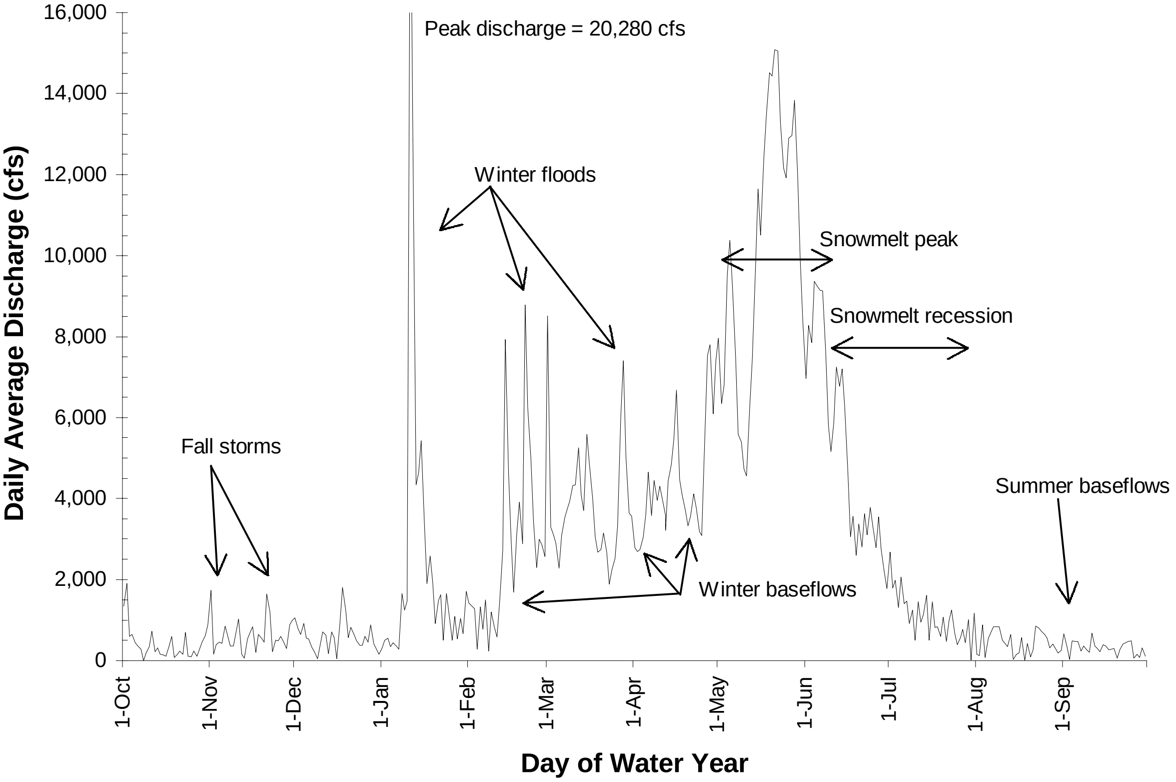

Figure 2-1. Tuolumne River at La Grange annual hydrograph for WY 1979 (NORMAL water year type) to illustrate the important hydrograph components.

NDPP regulation), and are presented in Appendix A. Analyses of streamflow patterns for daily average flow revealed characteristic patterns which we termed "hydrograph components". Important hydrograph components for the Tuolumne River were fall storm pulses, winter and summer baseflows, winter floods, spring snowmelt floods and snowmelt recession, and transition periods between components (Figure 2-1). These components were further analyzed to describe the variability in magnitude, timing, duration, and frequency, and rates of change of flow for five water year types. Additionally, a single hydrograph for the Tuolumne River was constructed by averaging daily streamflows for the entire period of record. Each hydrograph component uniquely influenced the morphology and function of the channel, as well as riparian vegetation patterns and chinook salmon life history characteristics. This approach was recently developed for evaluating the impacts of regulation on streamflow in the Trinity River, CA (USFWS 1999).

2.1.1.2. Annual water yield and water year types

The annual water yield for unimpaired flows at La Grange for WY1897 to 1999 was plotted to illustrate the variation in annual yield (Figure 2-2). Average annual unimpaired water yield for the Tuolumne River over the 102 years of record is approximately 1,900,000 acre-feet (af). Annual yield (Table 2-1) varied widely from a low of 454,000 af (WY1977) to 4.6 million af (WY1983). Annual water yields were then classified into five water year types based on the frequency distribution of annual yield. This water year classification is not meant to replace the classification system in the FSA, but is simpler and allows a more descriptive presentation of inter-annual variability[2].

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[2] The water year classification system used in the Settlement Agreement is based on the 60-20-20 San Joaquin Index, a formula that differentially weights three factors to determine a water year index: (1) the current year's estimated April-July unimpaired runoff (60%), (2) current year's estimated unimpaired October-March runoff (20%), and (3) the previous year's index (20%). This classification defines ten water year types for the lower Tuolumne River, with unequal occurrence probabilities.

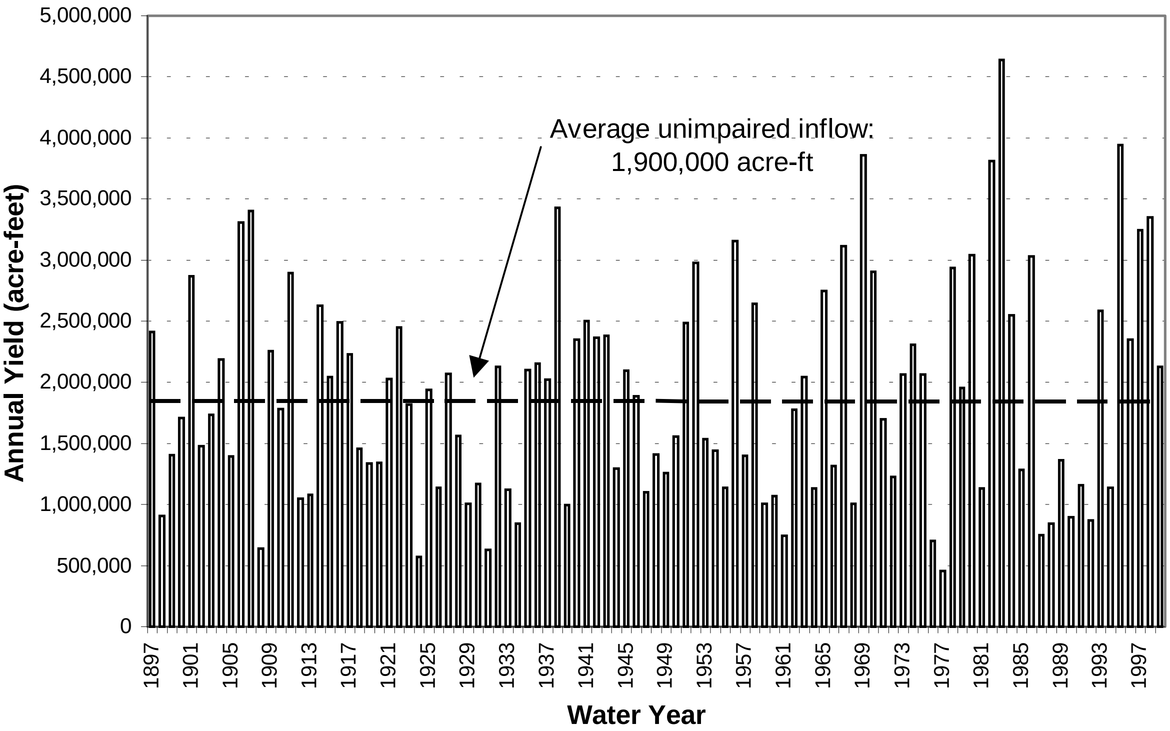


Figure 2-2 Annual unimpaired water yield of the Tuolumne River at La Grange, from WY 1897 to 1999.

The water year classification used in the Restoration Plan was developed by plotting WY1918 to WY1999 annual water yields as an exceedence probability (WY1897 to WY1917 were excluded because the reconstructed data were less reliable). The distribution was then divided symmetrically into five equally weighted classes separated by annual exceedence probabilities (p) of 0.80, 0.60, 0.40, and 0.20 (Figure 2-3) and named “Extremely Wet”, “Wet”, “Normal”, “Dry”, and “Critically Dry”. This classification system addresses the range of variability in the annual water yield and provides an equal probability for each class that a given water year will fall into that category (equally distributed around the mean), which in turn allows simpler interpretation of comparisons between water year types. Differences among and within water year classes have meaningful geomorphic and biological consequences, and will be discussed later in this chapter.

Annual hydrographs grouped into the five water year classes were then averaged to produce a single average hydrograph. Average water year hydrographs illustrate differences between water year classes, but mask natural flow variability within each class. To highlight the annual flow variability, we overlaid the water year average hydrographs with a single unimpaired annual hydrograph from a representative water year (Figures 2-4 to 2-8). We also included the FERC minimum baseflows. Water years 1967, 1940, 1946, 1985, and 1987 were selected as representative years for Extremely Wet, Wet, Normal, Dry and Critically Dry years, respectively. Water year class designations are also indicated on the annual hydrographs plotted for each water year (Appendix A).

2.1.1.3 Hydrograph components

Unimpaired hydrograph components and the associated variability in magnitude, timing, duration, and frequency were analyzed for each water year class by plotting and inspecting annual hydrographs to provide a mean or median value, peak value, and/or minima and maxima representative of each water year class (Table 2-2). Important hydrograph components are:

- Fall baseflows. Occurring between October 1 and December 20, these were relatively low flows punctuated by short duration, small magnitude fall floods. Fall baseflows were the unimpaired flows to which adult chinook salmon were adapted during the spawning phase of their life history. Average fall baseflows ranged from 300 cfs to 550 cfs during Critically Dry and Extremely Wet water years, respectively, and frequently exceeded 1,000 cfs during wetter fall seasons;
- Fall floods. Occurring between October 1 and December 20, these floods were generally of smaller magnitude than winter storms. Median peaks ranged from 1,400 cfs to 6,300 cfs for Critically Dry and Wet years, respectively, but exceeded 20,000 cfs seven times during unimpaired conditions, all during Extremely Wet and Wet water years;
- Winter baseflow. Occurring between December 21 and March 20, winter baseflows were low flows between individual storm events. Winter baseflows were maintained by the receding limbs of storm hydrographs and shallow groundwater discharge, and generally increased in magnitude and duration throughout the winter months as soils and groundwater tables rose. Flow conditions during winter months were highly variable, so determining baseflow was difficult. Wetter years generally exhibited higher winter baseflows. Extremely Wet years had baseflows ranging from 1,300 cfs to 4,400 cfs, averaging 2,800 cfs. Critically Dry years ranged from 300 cfs to 1,200 cfs, averaging 780 cfs;
- Winter floods. Typically occurring between mid-December and late-March, winter floods were generated by rainfall or rain-on-snow storm events. Larger magnitude, short duration floods caused by rainfall and rain-on-snow storm events typically peaked in late December through January, with moderate magnitude events extending through March. Winter floods were described two ways: the standard flood frequency analysis of instantaneous peak floods (USGS 1982), and peak daily average floods for

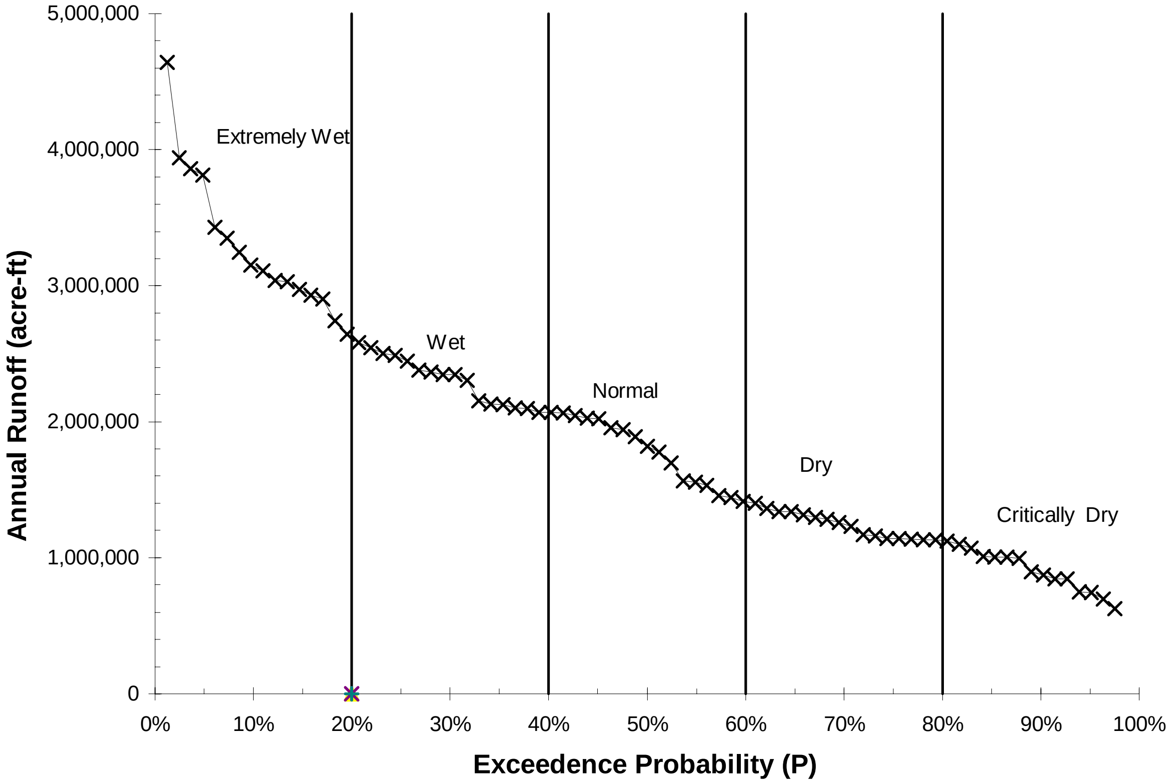


Figure 2-3. Cumulative plot of ranked annual water yields for the Tuolumne River at La Grange, showing exceedence probabilities of annual yield and water year classification scheme.

Table 2-1. Tuolumne River at La Grange annual water yield and water yield classification for unimpaired and post-NDPP regulated conditions. The water year classification is based on unimpaired water yield.

Water Year	Unimpaired water yield (acre-ft)	Post-NDPP water yield (acre-ft)	Water year classification (based on unimpaired water yield)	Rank (1-82)	Exceedence Probability
1897	2,408,626	N/A	NOT USED		
1898	904,929	N/A	NOT USED		
1899	1,405,080	N/A	NOT USED		
1900	1,709,988	N/A	NOT USED		
1901	2,868,440	N/A	NOT USED		
1902	1,478,285	N/A	NOT USED		
1903	1,732,731	N/A	NOT USED		
1904	2,186,807	N/A	NOT USED		
1905	1,394,306	N/A	NOT USED		
1906	3,309,416	N/A	NOT USED		
1907	3,402,943	N/A	NOT USED		
1908	641,423	N/A	NOT USED		
1909	2,253,531	N/A	NOT USED		
1910	1,784,531	N/A	NOT USED		
1911	2,895,247	N/A	NOT USED		
1912	1,049,518	N/A	NOT USED		
1913	1,081,250	N/A	NOT USED		
1914	2,624,557	N/A	NOT USED		
1915	2,044,411	N/A	NOT USED		
1916	2,488,186	N/A	NOT USED		
1917	2,226,657	N/A	NOT USED		
1918	1,456,903	N/A	Normal	47	59%
1919	1,337,742	N/A	Dry	53	66%
1920	1,340,043	N/A	Dry	52	65%
1921	2,026,884	N/A	Normal	36	45%
1922	2,447,486	N/A	Wet	21	26%
1923	1,819,087	N/A	Normal	41	51%
1924	570,826	N/A	Critically Dry	81	101%
1925	1,940,010	N/A	Normal	39	49%
1926	1,138,400	N/A	Dry	62	78%
1927	2,069,819	N/A	Wet	32	40%
1928	1,562,925	N/A	Normal	44	55%
1929	1,004,076	N/A	Critically Dry	71	89%
1930	1,166,851	N/A	Dry	59	74%
1931	627,292	N/A	Critically Dry	80	100%
1932	2,128,335	N/A	Wet	28	35%
1933	1,120,610	N/A	Dry	66	83%
1934	843,120	N/A	Critically Dry	76	95%
1935	2,102,592	N/A	Wet	30	38%
1936	2,152,228	N/A	Wet	27	34%
1937	2,022,282	N/A	Normal	37	46%
1938	3,429,698	N/A	Extremely Wet	5	6%
1939	995,539	N/A	Critically Dry	72	90%
1940	2,345,490	N/A	Wet	25	31%
1941	2,501,575	N/A	Wet	19	24%
1942	2,363,833	N/A	Wet	23	29%
1943	2,381,340	N/A	Wet	22	28%
1944	1,297,111	N/A	Dry	55	69%
1945	2,095,788	N/A	Wet	31	39%
1946	1,887,704	N/A	Normal	40	50%
1947	1,098,414	N/A	Critically Dry	67	84%
1948	1,412,392	N/A	Normal	49	61%
1949	1,256,930	N/A	Dry	57	71%
1950	1,557,473	N/A	Normal	45	56%

Table 2-1 cont.

Water Year	Unimpaired water yield (acre-ft)	Post-NDPP water yield (acre-ft)	Water year classification (based on unimpaired water yield)	Rank (1-82)	Exceedence Probability
1951	2,485,956	N/A	Wet	20	25%
1952	2,975,644	N/A	Extremely Wet	12	15%
1953	1,533,804	N/A	Normal	46	58%
1954	1,441,268	N/A	Normal	48	60%
1955	1,139,613	N/A	Dry	61	76%
1956	3,152,732	N/A	Extremely Wet	8	10%
1957	1,397,742	N/A	Normal	50	63%
1958	2,643,558	N/A	Extremely Wet	16	20%
1959	1,008,562	N/A	Critically Dry	69	86%
1960	1,067,594	N/A	Critically Dry	68	85%
1961	745,506	N/A	Critically Dry	78	98%
1962	1,776,171	N/A	Normal	42	53%
1963	2,045,209	N/A	Normal	35	44%
1964	1,131,801	N/A	Dry	64	80%
1965	2,744,866	N/A	Extremely Wet	15	19%
1966	1,313,905	N/A	Dry	54	68%
1967	3,110,883	N/A	Extremely Wet	9	11%
1968	1,005,905	N/A	Critically Dry	70	88%
1969	3,858,598	N/A	Extremely Wet	3	4%
1970	2,903,749	N/A	Extremely Wet	14	18%
1971	1,696,685	345,889	Normal	43	54%
1972	1,228,740	163,878	Dry	58	73%
1973	2,066,837	165,014	Wet	33	41%
1974	2,306,285	375,652	Wet	26	33%
1975	2,066,348	561,473	Wet	34	43%
1976	699,777	360,014	Critically Dry	79	99%
1977	454,334	67,115	Critically Dry	82	103%
1978	2,932,759	292,052	Extremely Wet	13	16%
1979	1,957,501	657,186	Normal	38	48%
1980	3,040,767	1,493,029	Extremely Wet	10	13%
1981	1,130,446	441,488	Dry	65	81%
1982	3,810,491	1,718,285	Extremely Wet	4	5%
1983	4,639,714	3,464,878	Extremely Wet	1	1%
1984	2,544,881	1,376,458	Wet	18	23%
1985	1,281,836	376,094	Dry	56	70%
1986	3,028,685	1,133,989	Extremely Wet	11	14%
1987	750,286	283,365	Critically Dry	77	96%
1988	843,629	77,660	Critically Dry	75	94%
1989	1,362,947	61,029	Dry	51	64%
1990	894,134	84,964	Critically Dry	73	91%
1991	1,160,524	83,115	Dry	60	75%
1992	870,146	80,561	Critically Dry	74	93%
1993	2,581,784	240,952	Extremely Wet	17	21%
1994	1,136,409	187,313	Dry	63	79%
1995	3,939,017	2,184,597	Extremely Wet	2	3%
1996	2,348,979	1,183,331	Wet	24	30%
1997	3,245,211	1,958,532	Extremely Wet	7	9%
1998	3,348,765	1,998,252	Extremely Wet	6	7%
1999	2,127,404	973,206	Wet	29	35%
Average annual yield	1,906,505	772,047			

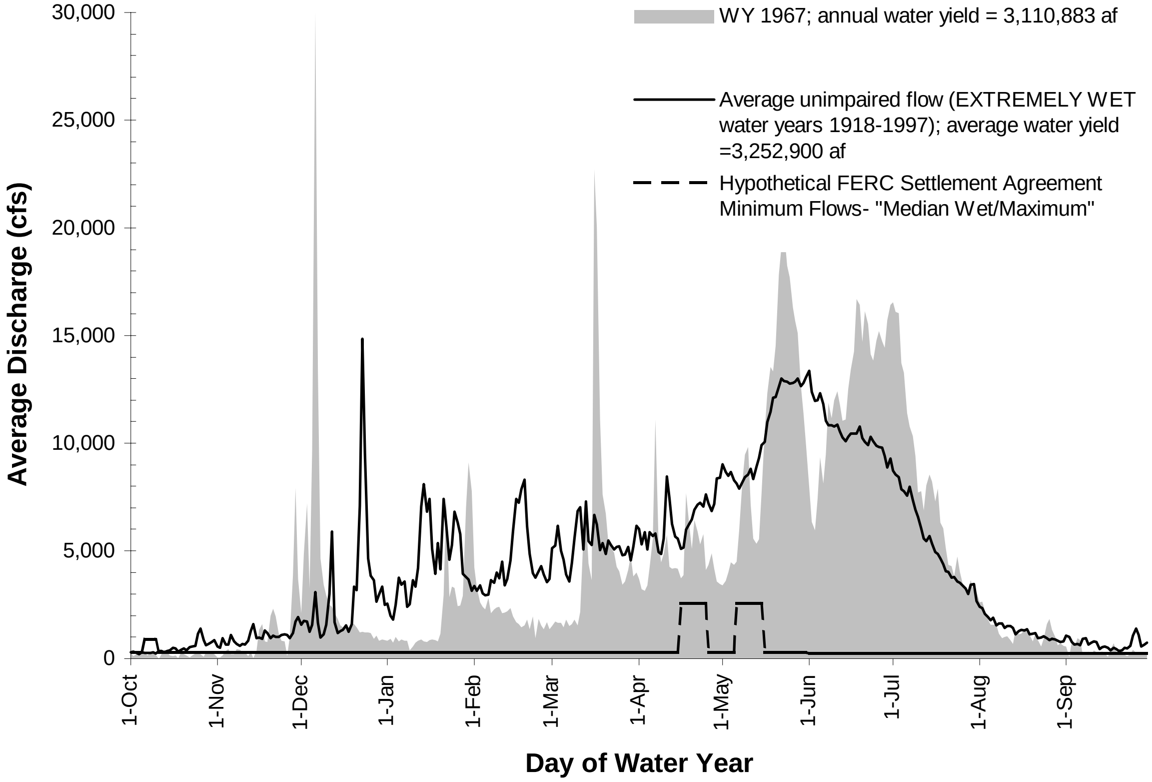


Figure 2-4. Average and representative (WY 1967) EXTREMELY WET water year annual hydrographs for the Tuolumne River at La Grange.

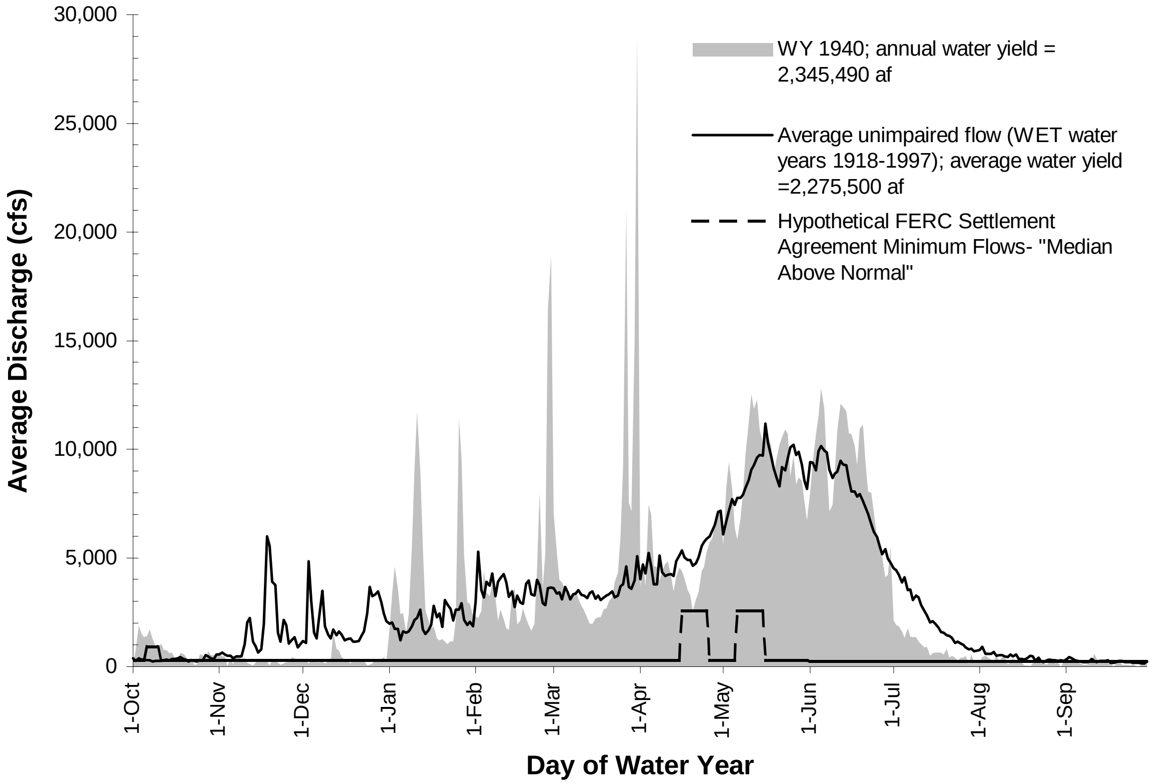


Figure 2-5. Average and representative (WY 1940) WET water year annual hydrographs for the Tuolumne River at La Grange.

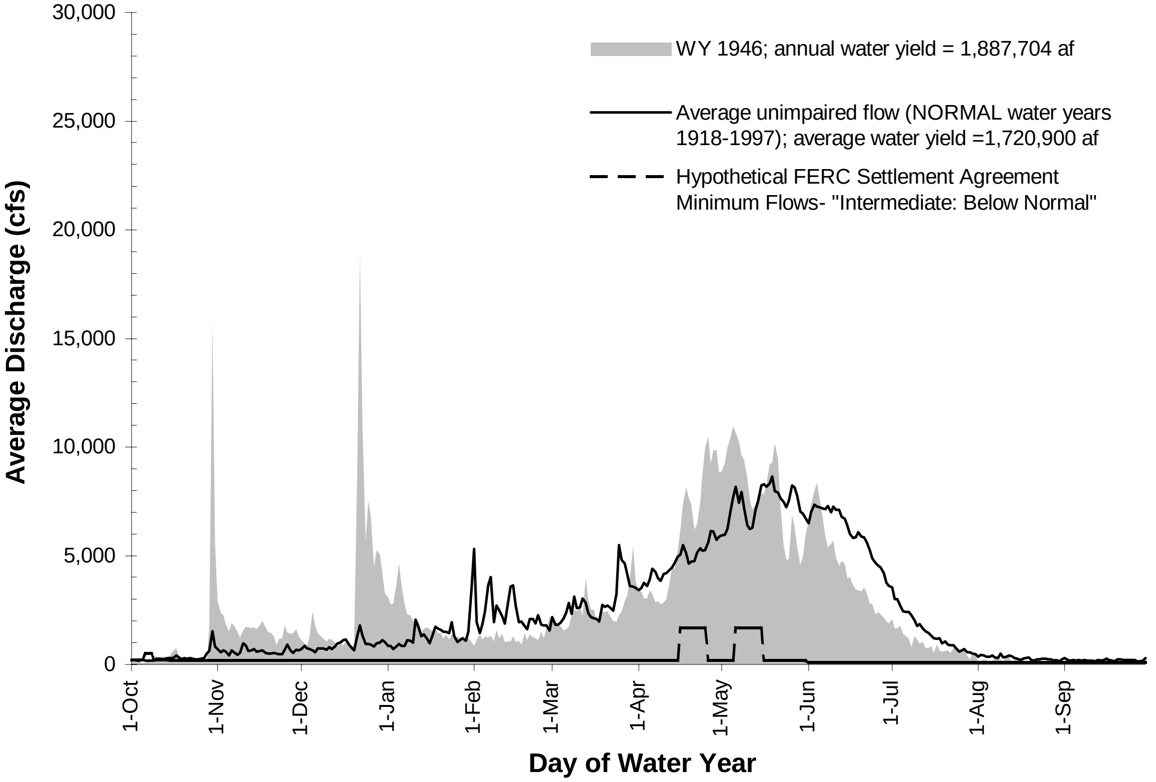


Figure 2-6. Average and representative (WY 1946) NORMAL water year annual hydrographs for the Tuolumne River at La Grange.

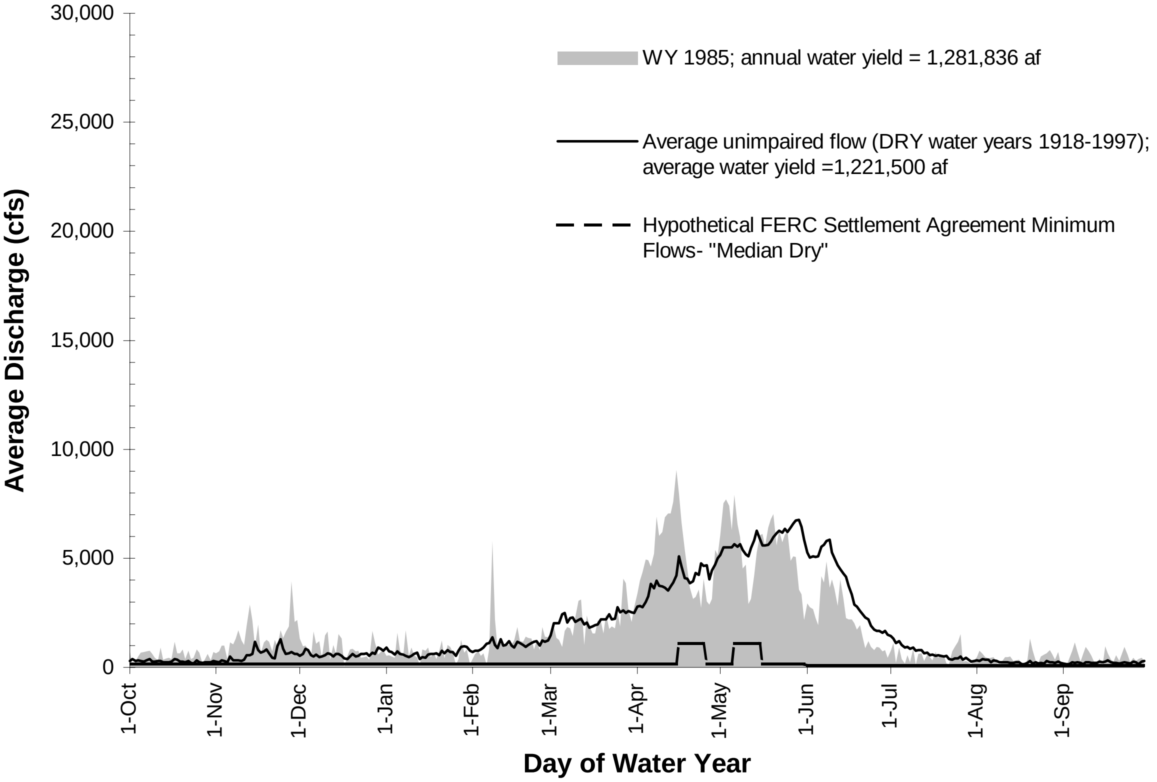


Figure 2-7. Average and representative (WY 1985) DRY water year annual hydrographs for the Tuolumne River at La Grange.

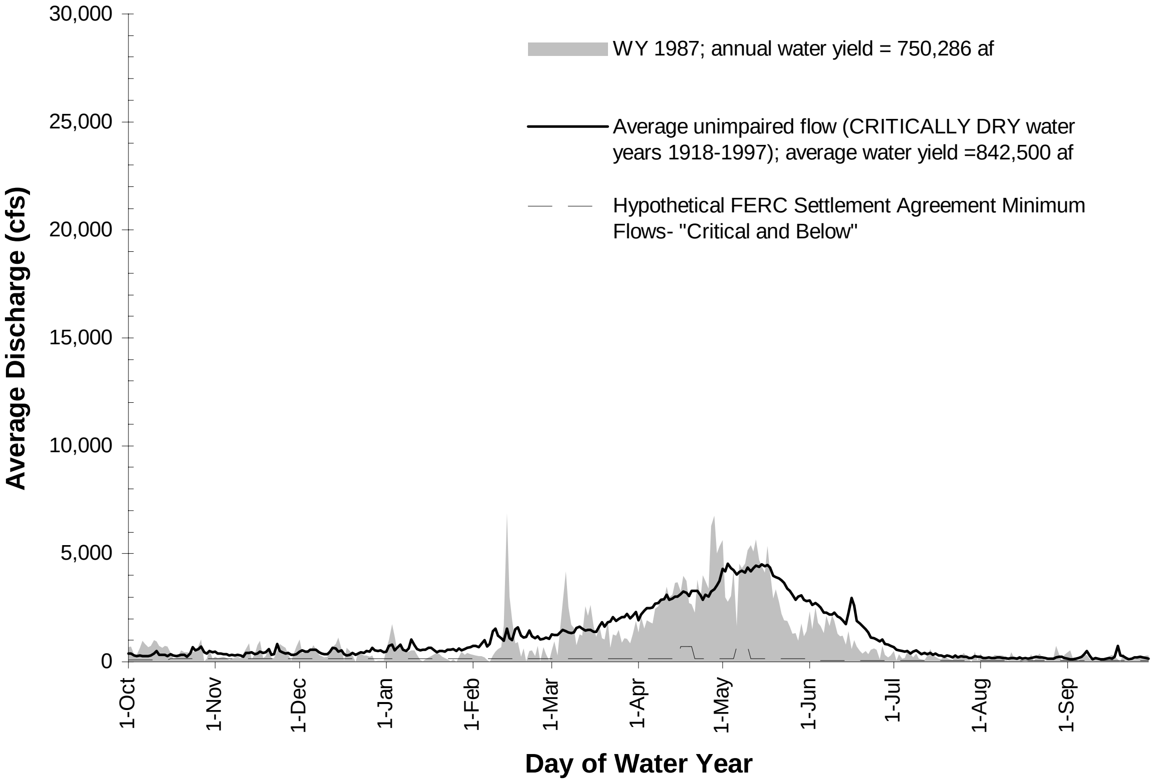


Figure 2-8. Average and representative (WY 1987) CRITICALLY DRY water year annual hydrographs for the Tuolumne River at La Grange.

each water year class. Flood frequency curves for the La Grange gaging station were based on the annual maximum series for pre-NDPP and post-NDPP hydrology, and included raw data and a log-Pearson Type III distribution fit to log-transformed data (Figure 2-9). The 1.5- year recurrence interval flood for unimpaired conditions was 8,400 cfs; the 5-year flood was approximately 25,000 cfs and the 25-year flood was approximately 53,000 cfs (Table 2-3). The flood of record was approximately 130,000 cfs, and occurred in 1862 and 1997. The annual maximum daily average flow was also analyzed for each water year class. Magnitude of the median peak flood ranged from 2,900 cfs to 19,000 cfs for Critically Dry to Wet years, respectively, with maxima ranging between 50,000 cfs and 60,000 cfs during Wet and Extremely Wet water years. Dry and Critically Dry years had relatively lower daily average flood peaks, but still ranged above 15,000 cfs for the Dry year maximum flood (Table 2-2);

Table 2-3. Tuolumne River at La Grange pre- and post-NDPP annual maximum series flood frequency data.

	USGS La Grange Gage
Pre-NDPP 1.5-yr flood	8,670 cfs
Post-NDPP 1.5-yr flood	3,020 cfs
Percent of pre-NDPP	35%
Pre-NDPP 5-yr flood	25,230 cfs
Post-NDPP 5-yr flood	7,569 cfs
Percent of pre-NDPP	30%
Pre-NDPP 10-yr flood	37,574 cfs
Post-NDPP 10-yr flood	8,429 cfs
Percent of pre-NDPP	22%

Table 2-2. Important components of annual unimpaired hydrographs of daily average flow for the Tuolumne River at La Grange, analyzed for five different water year classes. Based on 1918 to 1997 period.

Hydrograph Components	**Extremely Wet**	**Wet**	**Normal**	**Dry**	**Critica**
(probability of exceedence)	20%	40%	60%	80%	10
(annual water yield, million acre-feet)	>2.55 maf	2.05-2.55 maf	1.39-2.05 maf	1.1-1.39 maf	<1.
Fall baseflows (Oct 1-Dec 20)					
Baseflow Average	500	400	400	400	3
Minimum	230	90	90	130	1
Maximum	1,700	1,600	900	800	8
Fall Floods (Oct 1 - Dec 20)					
Median Peak Magnitude	5,300	6,400	2,700	1,800	1,
Maximum	74,400	67,000	15,800	10,600	8,
Median Date of First Fall Storm	4-Nov	18-Nov	30-Oct	18-Nov	25
Winter Baseflow (Dec 21-Mar 20)					
Baseflow Average	2,800	2,100	1,300	900	8
Minimum	1,400	1,500	430	570	2
Maximum	4,500	2,800	2,600	1,700	1,
Winter Floods (Dec 21-Mar 20)					
Average Peak Magnitude	23,700	21,200	14,000	7,300	3,
Median Peak Magnitude	11,800	19,400	10,000	6,100	2,
Minimum	8,500	10,300	5,100	2,900	2,
Maximum	47,600	61,000	38,100	15,600	6,
Snowmelt Floods (Mar 21-Aug 5)					
Average Peak Magnitude	13,400	11,200	8,600	6,800	4,
Median Peak Magnitude	17,500	15,400	12,600	9,600	6,
Minimum	12,200	11,600	10,000	7,400	5,
Maximum	52,100	38,400	43,400	14,400	15
Snowmelt recession					
Median Date of Peak	1-Jun	16-May	19-May	29-May	3-
Seasonal Duration of Runoff	4-Sep	21-Aug	16-Aug	13-Aug	11
Summer Baseflow (July 15 - Oct 15)					
Baseflow Average	600	280	220	220	1
Minimum	400	170	120	130	[illegible]
Maximum	2,300	400	600	400	2

- Snowmelt floods. They were of lower magnitude and longer duration than winter floods. Prior to regulation and diversion, this component of the annual hydrograph was the largest contributor to the total annual water yield, with large magnitude and sustained duration floods peaking from late April to early June, then receding in July and August (Figure 2-10). The mean and median peak magnitudes, and the range of snowmelt floods were determined for each water year class (Table 2-2). The median peak floods ranged from 6,000 cfs to 17,000 cfs for Critically Dry and Extremely Wet years, respectively, but historically ranged as high as 52,000 cfs (the computed inflow into New Don Pedro Reservoir on 4/11/1982; this flood, a rain-on-snow event, was attenuated by NDPP and peaked at 8,150 cfs at La Grange on 4/15/1982). Dry and Critically Dry water years had moderate magnitude snowmelt peaks ranging from 5,000 cfs to 15,000 cfs;
- Snowmelt recession. Connecting the snowmelt peak to summer baseflows, the snowmelt recession extended into summer, generally occurring earlier in Dry and Critically Dry years (July), and later in Extremely Wet water years (August). Recession rates ranged from 780 cfs/day during the steepest portion of the recession to 112 cfs/day towards the end of recession during Extremely Wet water year types, and ranged from 400 cfs/day to 95 cfs/day for Normal and Dry water year types (Figures 2-4 to 2-8). The duration and rate of snowmelt recession had ecological significance to numerous biological populations within the Tuolumne River corridor;
- Summer baseflow. Beginning at the cessation of the spring snowmelt hydrograph, summer baseflows occurred until the first fall storms increased streamflows. Summer baseflows represented minimum annual flow conditions, historically averaging from 150 cfs during Critically Dry water years, to above 600 cfs during Extremely Wet water years. During some Extremely Wet water years, the summer baseflow component was obscured within the snowmelt recession limb and fall floods, and minimum annual flow conditions were unusually high. Conversely, during drought years the summer baseflow occasionally dropped below 100 cfs.

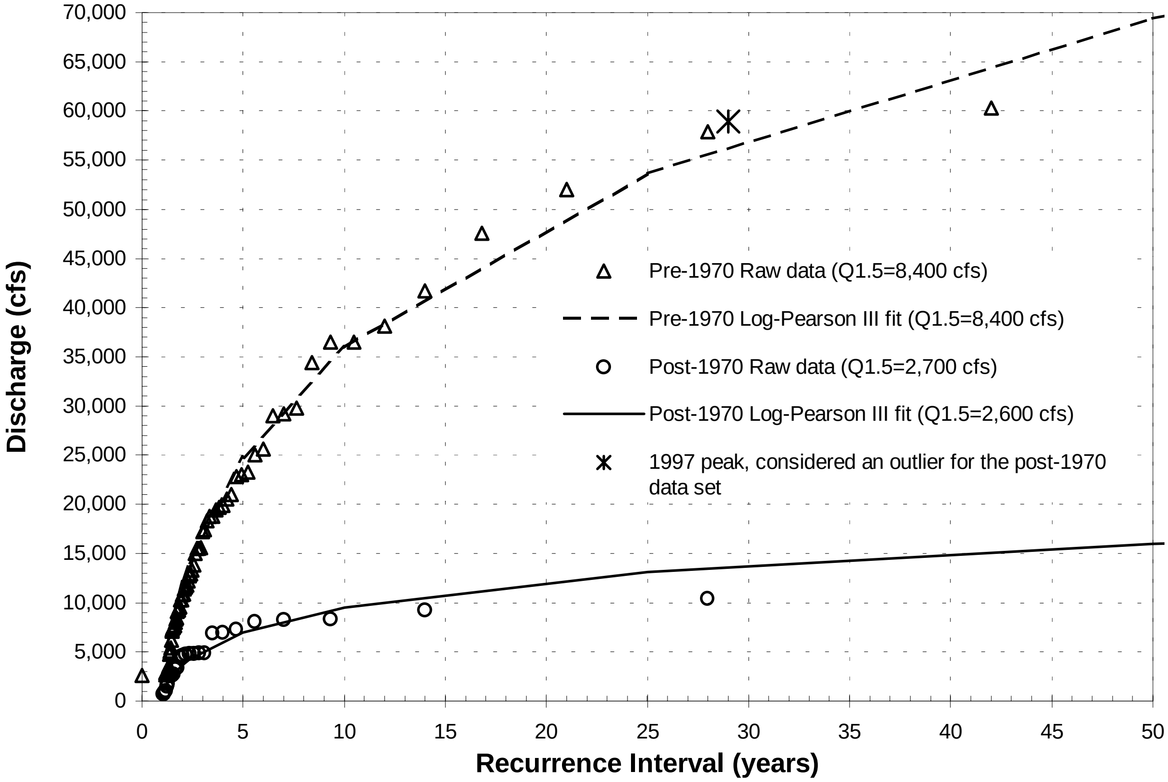


Figure 2-9. Annual maximum flood frequency curves for unimpaired and post-NDPP periods at La Grange (STN 11-289650, Drainage Area = 1,900 sq. mi.)

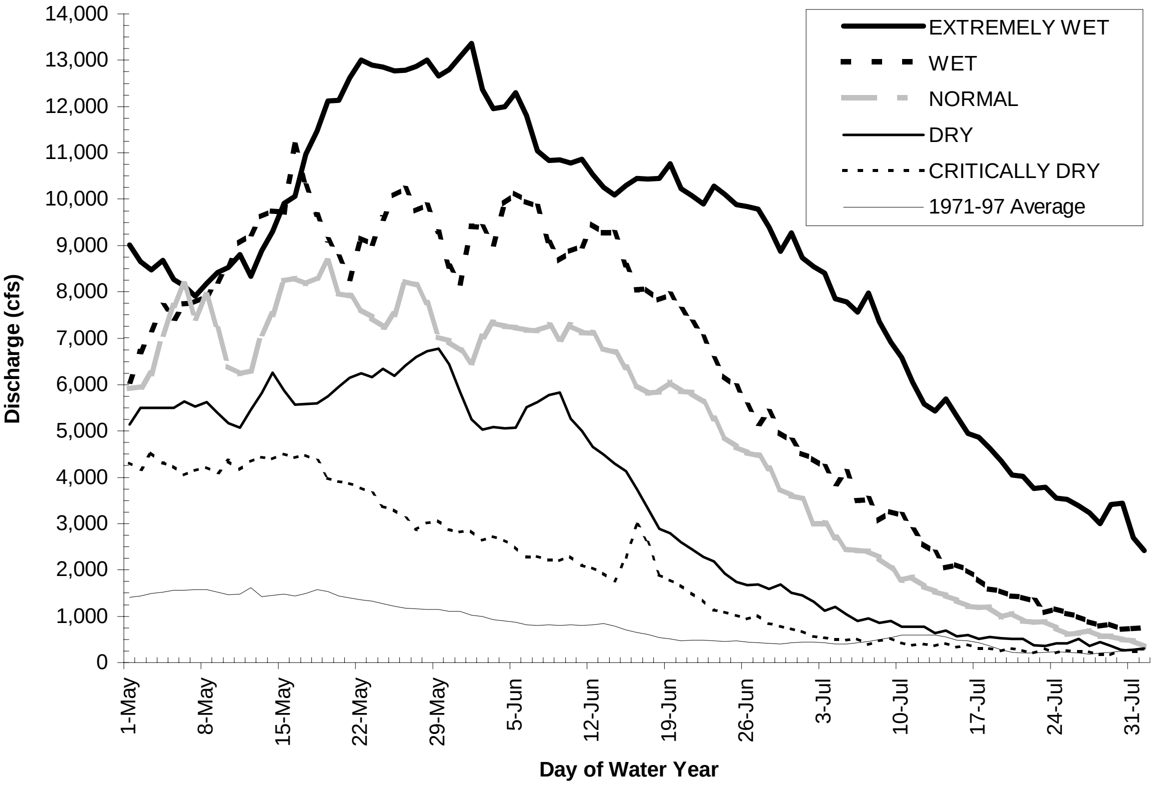


Figure 2-10. Tuolumne River at La Grange, unimpaired annual hydrographs during snowmelt recession for each water year class, and the 1971-1997 average hydrograph for the impaired post-NDPP period.

2.1.1.4. *Flow duration curves*

The daily average flow duration curve illustrates the relationship between the frequency and magnitude of streamflows. Flow duration curves were developed for both the unimpaired period and the post-NDPP period at the La Grange gaging station (Figure 2-11). Flow duration curves offer limited description of streamflow because they mask inter-annual and seasonal variability, but are useful in highlighting the changes to streamflow caused by regulation. For example, the 50% exceedence flow for the Tuolumne River (i.e., the *median* annual flow, or the flow that was exceeded 50% of the days), was reduced from 1,064 cfs to 224 cfs by NDPP regulation. The *mean* annual flow for the Tuolumne River for the unimpaired period of record was 2,544 cfs. The post-NDPP mean annual flow was reduced to 944 cfs, a 60% reduction.

2.1.2. Regulated flow regime

Disruption of natural streamflow patterns on the Tuolumne River began in the 1850's with early gold mining diversion ditches. However large-scale diversions began as early as the 1870s with construction and diversion at Wheaton Dam (1871) which was replaced by La Grange Dam (1893). These early dams and diversions lowered summer baseflows, but were too small to significantly affect other hydrograph components. More substantial water storage and flood flow modifications began with construction of Don Pedro Reservoir (290,000 af storage capacity) and Hetch Hetchy Reservoir (206,000 af storage capacity) in the 1920's. The storage capacity of these reservoirs was 26% of the mean annual water yield. CCSF began exports in 1923. Hetch Hetchy Dam was raised in 1937 to increase storage capacity to 360,000 af. Lake Lloyd on Cherry Creek added another 268,000 af of storage in the basin in 1955. The storage capacity of New Don Pedro Reservoir (2.03 million af) now exceeds the mean annual water yield for the entire Tuolumne River basin (1.906 million af). With the large watershed storage capacity and minimum instream flow requirements (1971 to present), the New Don Pedro Project severely diminished the magnitude, timing, duration, and frequency of hydrograph components in the post-NDPP era.

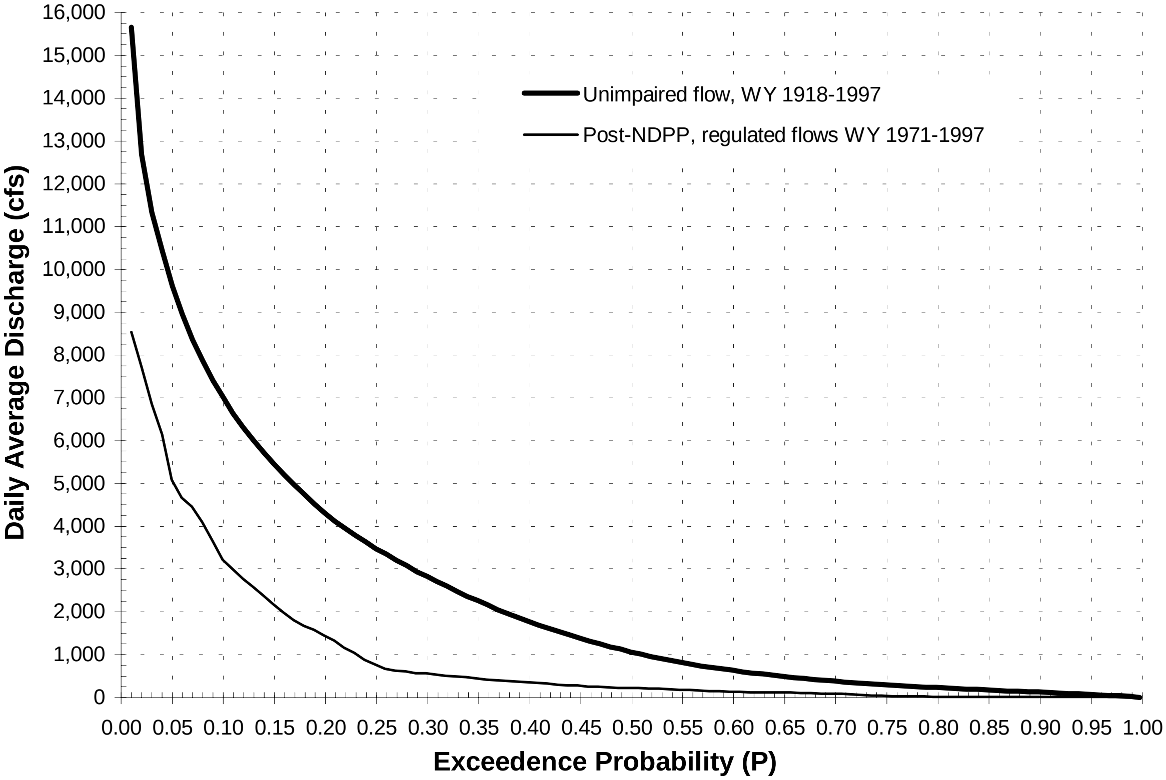


Figure 2-11. Daily average flow duration curves for unimpaired and post-NDPP periods at La Grange.

As a result of streamflow regulation and diversion, the flow regime on the Tuolumne River is vastly different from the unimpaired flow regime presented above. Article 37 of the NDPP FERC license requires minimum instream flows to protect fishery resources. In 1971, these instream flows were set at 64,000 af during Dry years (FERC designation), and 123,000 af in water years in which mean annual reservoir inflow or water yield exceeded 1 million af (67% exceedence, Table 2-4). Streamflows were augmented in the 1996 NDPP FERC license amendment, resulting in significantly increased minimum instream flow requirements, ranging from 94,000 af in Critical & Below water years (FERC designation), up to 300,000 af in water years above 50% exceedence (Table 2-5). Hydrograph components were analyzed for the post-NDPP hydrologic regime, and compared to the hydrograph components of the natural flow regime (Figure 2-12).

2.1.2.1. Annual hydrographs

Annual hydrographs for regulated water years 1971 to 1999 were prepared using streamflow data from the La Grange gaging station (Appendix A). Annual streamflow patterns have changed significantly by NDDP regulation, including:

- loss of inter-annual and seasonal variability;
- disruption and/or complete loss of hydrograph components;
- reduction in peak flows;
- reduction in baseflows.

These changes will be elaborated upon in the following sections.

2.1.2.2. Annual water yield

The average annual water yield below La Grange Dam has been reduced from 1.906 million af to 719,000 af, a 62% reduction in average annual yield. The lowest post-NDPP water yield was 61,029 af, occurring in 1989. The highest post-NDPP water yield was 3.46 million af, occurring in 1983.

Table 2-4. Minimum flow releases from NDPP as required by Article 37 of the original FERC License (1971 to 1995).

Period	**Schedule A Normal Year (unimpaired inflow > 1,000,000 af)**	**Schedule B Dry Year (unimpaired inflow between 750,000 and 1,000,000 af)**
	(cfs)	
Pre-season flushing flow	2,500	
October 1-15	200	50
October 16-31	250	200
November	385	200
December 1-15	385	200
December 16-31	280	135
January	280	135
February	280	135
March	350	200
April	100	85
May-September	3	3
Annual minimum release (acre-feet)	123,210	64,040

2.1.2.3. Hydrograph components

Hydrograph components were not analyzed by specific water year class in the post-NDPP period because the data set was smaller for regulated water years, and regulation eliminated much variability between water years. Changes are summarized below for the effect of streamflow regulation on each hydrograph component. In general, minimum instream flows were determined by the 1971 FERC license flow schedule, presented in Table 2-4.

- <u>Fall baseflows</u> are now determined by the FERC Settlement Agreement revised minimum flow schedule (Table 2-5), and is the minimum flow component adhered to most because reservoir storage is typically low following the summer diversion season (in contrast, winter baseflows occasionally are augmented by flood control releases). Baseflows are prescribed for the period Oct 1 to May 31 by the minimum flow schedule, and range between 100 cfs and 200 cfs for the drier 50% exceedence water year types, and 300 cfs for wetter 50% exceedence conditions. The effect of regulation was evident in all annual hydrographs. Previously variable streamflows are now held constant to maximize "weighted usable area" for spawning.
- <u>Fall floods</u> were eliminated by NDPP regulation in most water years, and were replaced with minimum instream flows ranging from 100 cfs to 300 cfs. Small "attraction pulse flows" usually less than 2,000 cfs and dependent on water year class, were released in wetter water years.
- <u>Winter baseflow</u> during the post-NDPP period has been reduced, with a median of 1,080 cfs. While this value is higher than the FERC minimum instream flow requirements, it is still comparable to a Dry water year in the unimpaired regime. Flow releases higher than FERC requirements occur during Wet and Extremely Wet water years when inflow rates and flood control requirements dictate higher streamflow releases from the NDPP.
- <u>Winter floods</u> have been severely diminished by NDPP regulation, with the frequency and magnitude of winter floods reduced. The 1.5 year recurrence flood ("approximate bankfull flow") was 8,400 cfs unimpaired (Figure 2-9) as compared to 2,600 cfs under post-NDPP conditions. Additionally, ACOE requires that flood control releases not exceed 9,000 cfs at the Modesto gage. This flood control limit has been exceeded only three times since NDPP operation began, in WY1983, WY1995, and the flood of January 1997, which peaked at 60,000 cfs. The turbine capacity of the NDPP powerhouse is about 5,500 cfs, so winter releases are frequently in the range 4,500 cfs to 5,500 cfs. Therefore, maximum annual winter floods post-NDPP are typically less than 5,500 cfs, with a low of 409 cfs in WY1977.
- <u>Snowmelt floods</u> have been eliminated from the annual hydrograph by NDPP operation, and replaced with Settlement Agreement-mandated spring pulse flows intended to stimulate smolt emigration. Water volumes available for spring pulse flows range from 11,091 af (comparable to 5,600 cfs for one day) to 89,882 af (comparable to 5,040 cfs for 9 days). Daily average flows for May and June at La Grange were reduced from 7,231 cfs unimpaired to 1,371 cfs actual flow (May), and 5,938 cfs unimpaired to 898 cfs actual flow (June). Summer minimum instream flows established by the FERC NDPP license begin June 1.

Table 2-5. Revised minimum flow releases from NDPP required by FERC License article 37 amendment (1995 to present).

Year Type	Critical & Below	Median Critical	Intermediate C-D	Median Dry	Intermediate D-BN	Median Below Normal	Intermediate BN-AN	Median Above Normal	Intermediate AN-W	Media Max
% Occurrence	6.4%	8.0%	6.1%	10.8%	9.1%	10.3%	15.5%	5.1%	15.4%	13
October 1- October 15	100 cfs 2,975 ac-ft	100 cfs 2,975 ac-ft	150 cfs 4,463 ac-ft	150 cfs 4,463 ac-ft	180 cfs 5,355 sc-ft	200 cfs 5,950 ac-ft	300 cfs 8,925 ac-ft	300 cfs 8,926 ac-ft	300 cfs 8,926 ac-ft	30 8,92
Attraction Pulse Flow	none	none	none	none	1,675 ac-ft	1,736 ac-ft	5,950 ac-ft	5,950 ac-ft	5,950 ac-ft	5,95
October 16-May 31	150 cfs	150 cfs	150 cfs	150 cfs	180 cfs	175 cfs	300 cfs	300 cfs	300 cfs	30
Outmigration Puse Flow	11,091 ac-ft	20,091 ac-ft	32,619 ac-ft	37,060 ac-ft	35,920 ac-ft	60,027 ac-ft	89,882 ac-ft	89,882 ac-ft	89,882 ac-ft	89,88
June 1- September 30	50 cfs 12,099 ac-ft	50 cfs 12,099 ac-ft	50 cfs 12,099 ac-ft	75 cfs 18,149 ac-ft	75 cfs 18,149 ac-ft	75 cfs 18,149 ac-ft	250 cfs 60,496 ac-ft	250 cfs 60,496 ac-ft	250 cfs 60,496 ac-ft	25 60,49
Volume (acre-feet)	94,000	103,000	117,016	127,507	142,502	165,002	300,923	300,923	300,923	30

- Snowmelt recession was also altered by NDPP operation. Spring pulse flows are established for fishery management purposes only, and the receding limb is often early, short and steep, except in wetter years when flood control releases occur.
- Summer baseflows have been reduced by NDPP operation. The median baseflow for August 1 through September 30 was 37 cfs for the period WY1971 to 1997, and was as low as 0 cfs during several sustained drought periods. Beginning in 1995, summer minimum instream flows from June 1 through September 30 were increased by the FERC NDPP license (Table 2-5), and ranged from 50 cfs and 250 cfs for Critically Dry and Normal-Wet water years, respectively.

2.2. FLUVIAL GEOMORPHOLOGY

2.2.1. Fluvial geomorphic processes

Restoration scientists and resource managers are increasingly recognizing that *integrating fluvial processes with the life histories of biological resources to rehabilitate riverine ecosystems* is a fundamentally sound approach to restoring native fish and wildlife populations (Stanford et al. 1996) (NRC 1996) (Lichatowich 1995) (Hill et al. 1991) (USFWS 1999). This section describes historical fluvial processes in the Tuolumne River, and how these processes have changed in response to watershed development and land use.

Fluvial geomorphology is the study of landform development by processes associated with running water, and the erosion and transport of sediments. Fluvial processes form and maintain the river channel, the river corridor, and the alluvial valley. The primary processes are coarse and fine sediment transport, sediment deposition, and channel migration. The river's physical form (and therefore the structural complexity of habitat) is governed by the interaction of these fluvial processes with streamflow hydrology, geological controls, riparian influences, and human influences. These interactions are numerous and complex. Simplifying fundamental cause and effect relationships helps illustrate how land use practices initiate channel responses.

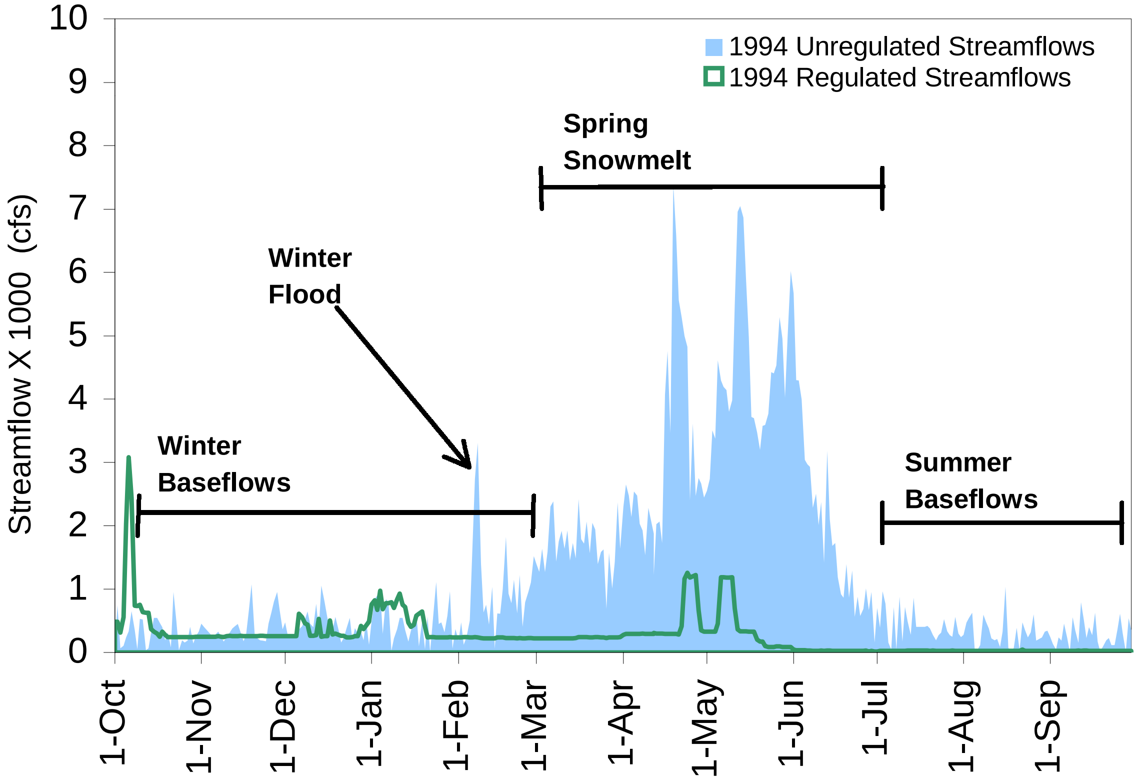


Figure 2-12. Tuolumne River at La Grange annual hydrograph of unimpaired streamflow and post-NDPP streamflow for WY 1994 (DRY water year type), showing changes in hydrograph components from unimpaired conditions.

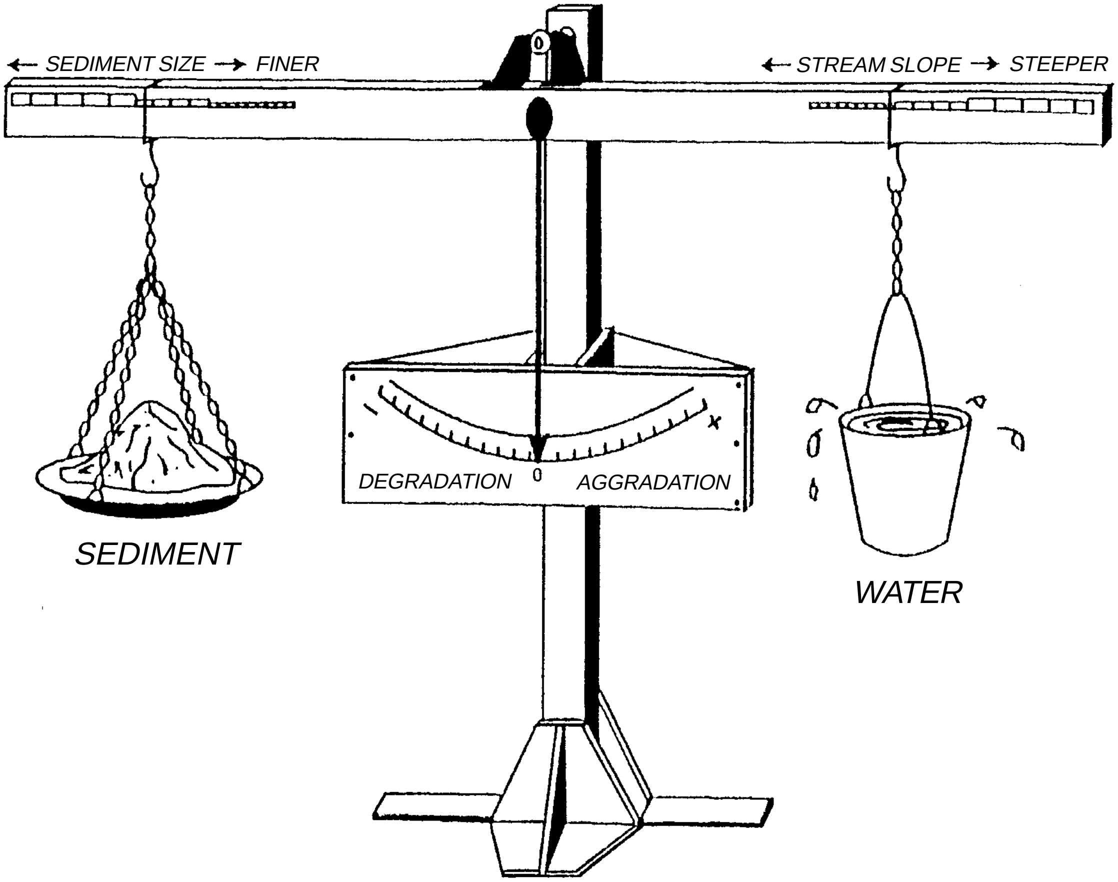


Figure 2-13. Conceptual flow-sediment balance necessary for channel equilibrium, and channel response to disequilibrium (from Lane 1955).

Lane (1955) provided a simple formula to illustrate the way in which rivers balance slope, sediment particle size, sediment transport, and streamflow to maintain a dynamic equilibrium:

$$Q_w * S \mu Q_s * D_{50} \qquad (2\text{-}1)$$

where Q_w = stream discharge, S = slope, Q_s = sediment discharge , and D_{50} = median grain size (Figure 2-13).

A balance in the sediment transport capacity provided by the high flow regime with sediment supplied from the watershed over time and distance results in a “dynamic quasi-equilibrium,” in which sediment is mobilized, transported, and deposited. The channel migrates (dynamic), but the size and shape of the channel remain similar (equilibrium) (Schumm 1977). While this presentation of the quasi-dynamic equilibrium concept of sediment supply and transport is considerably simplified, its use as a quantifiable objective to balance flow and sediment supply is a powerful tool for assessing fluvial processes. It also helps predict channel responses to altered flow and sediment regimes.

Dams, aggregate extraction, agricultural and urban encroachment, and other land uses have caused sediment imbalances in the Tuolumne River channel. For example, reduced magnitude, duration, and frequency of high flows imposed by upstream dams has allowed fine sediment to accumulate in the river. Elimination of coarse sediment supply below the dams and accumulation of fine sediment from reduced flood flows have degraded chinook salmon spawning habitat.

The impact of these imbalances is also a function of distance along the Tuolumne River because the relationships between slope, sediment particle size, sediment transport, and streamflow change longitudinally as the Tuolumne River travels from headwaters to the San Joaquin River. Differences in valley slope, valley confinement, particle size, channel forming discharge, and vegetation create local variation in channel morphology. Fluvial processes and the resultant channel morphology depend on these longitudinal differences, and must be incorporated into restoration planning.

2.2.2. Geomorphic reach delineation

Downstream of La Grange Dam, the Tuolumne River can be divided into two distinct geomorphic zones broadly defined by the channel slope and bed material: the sand-bedded zone extends from RM 0.0 to RM 24.0, and the gravel-bedded zone extends from RM 24.0 to RM 52.0 (Figure 2-14). The transition from gravel-bedded to sand-bedded zones is a remnant of pre-NDPP processes: where the valley widens and slope decreases, the river was unable to transport gravel and cobble-sized particles. These larger particles deposited in upstream reaches, while sand continued to be transported downstream. During moderate and larger flows the dominant clast in transport is thus different in each zone. The transition from gravel-bedded to sand-bedded at approximately RM 24 caused a noticeable change in planform morphology: in the sand-bedded zone sinuosity increased, amplitude increased, meanders became more tortuous, and channel migration was more continuous than in the upstream gravel-bedded zone. Channel morphology is characteristically a meandering alternate bar morphology, rather than the less sinuous alternate bar morphology prevalent upstream. These changes also influenced the composition of woody riparian species.

These two geomorphically-based zones were subdivided into seven reaches based on present and historical land uses, the extent and influence of urbanization, valley confinement from natural and anthropogenic causes, channel substrate and slope, and salmon habitat quality. Differences between these reaches warrant unique restoration visions and strategies. The major reaches are:

REACH 1 (RM 0-10.5): “Lower Sand-bedded Reach,” defined by agricultural land use and encroachment (row crops and vineyards), no valley confinement during high flows, low slope (<0.0003), and a sand-bedded channel.

REACH 2 (RM 10.5-19.3): “Urban Sand-bedded Reach,” defined by agricultural land use (row crops and orchards) and urban encroachment, moderate valley confinement during high flows, low slope (<0.0003), and a sand-bedded channel. The City of Modesto is centered in this reach, and Dry Creek enters midway through the reach.

REACH 3 (RM 19.3-24.0): “Upper Sand-bedded Reach,” defined by agricultural land use (orchards) and rural encroachment (suburban ranch homes), low valley confinement during high flows, low slope (<0.0003), and a sand bedded channel. The upstream end of this reach marks the transition from gravel-bedded channel to sand-bedded channel.

REACH 4 (RM 24.0-34.2): “In-channel Gravel Mining Reach,” defined by instream aggregate extraction pits, dike encroachment (intended to isolate off-channel aggregate extraction pits), agricultural land use (orchards) and encroachment, low valley confinement during high flows downstream of Waterford (RM 31), large valley confinement during high flows upstream of Waterford, moderate slope (0.0003 near Fox Grove to 0.0015 near Waterford), and a gravel-bedded channel.

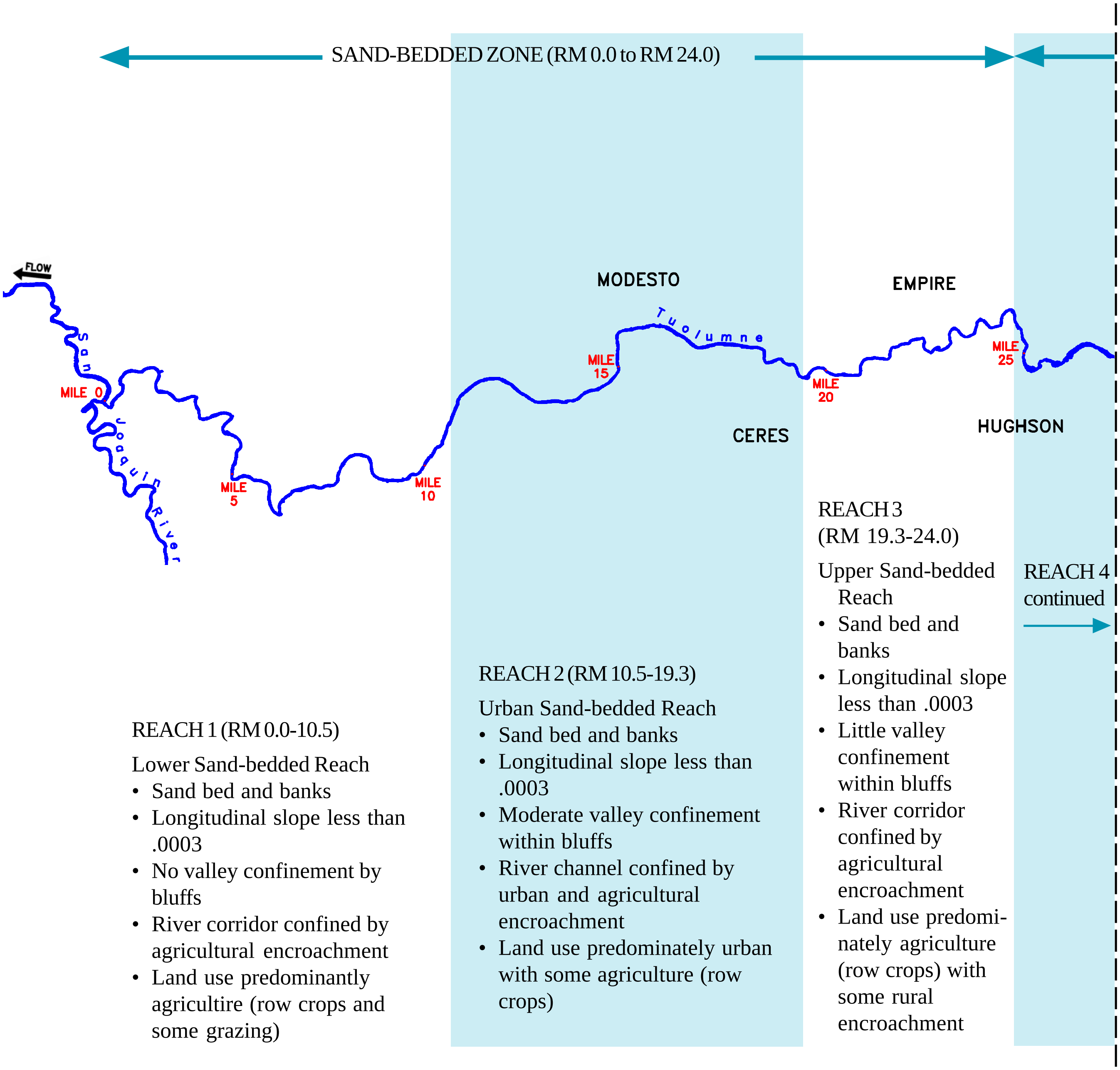
REACH 5 (RM 34.5-40.3): “Gravel Mining Reach,” defined by extensive off-channel aggregate extraction pits, dike encroachment intended to isolate the pits from the river, agricultural land use and encroachment (orchards and row crops), low valley confinement, moderate slope (0.0010 to 0.0015), and a gravel-bedded channel.

REACH 6 (RM 40.3-45.5): “Dredger Tailing Reach,” defined by remnant gold dredger tailings on floodplains, a fragmented channel with multiple connected backwaters, agricultural land use (grazing), low valley confinement during high flows, moderate slope (0.0010 to 0.0015), and a gravel-bedded channel. Some of the dredger tailings were removed during aggregate extraction operations and NDPP construction. The fragmented low water channel left by dredging activities has not appreciably re-adjusted over time.

REACH 7 (RM 45.5-52.1): “Dominant Salmon Spawning Reach,” defined by disproportionately high salmon spawning use, agricultural land use (grazing), low valley confinement during high flows, moderate slope (0.0010 to 0.0015), and a gravel-bedded channel. Construction of the NDPP in 1970 removed the extensive dredger tailings throughout the reach for use as construction materials for the New Don Pedro Project. This activity and subsequent channel reconstruction resulted in a single-thread meandering low water channel with low bankfull confinement. The quality and availability of spawning habitat in this reach surpasses that of all other reaches.

The slope estimates presented above are generalized from the 1969 USGS Channel Capacity Study (Figure 2-15) and from 1996 water surface profile measurements during high flows equal to or greater than 5,300 cfs.

The following section discusses historic channel morphology and fluvial processes on the Tuolumne River. This discussion differentiates the sand-bedded zone from the gravel-bedded zone; however, because a primary distinction between the seven reaches is the degree of human disturbance, an historical differentiation between the seven reaches is not attempted.



REACH 1 (RM 0.0-10.5)

Lower Sand-bedded Reach
- Sand bed and banks
- Longitudinal slope less than .0003
- No valley confinement by bluffs
- River corridor confined by agricultural encroachment
- Land use predominantly agricultire (row crops and some grazing)

REACH 2 (RM 10.5-19.3)

Urban Sand-bedded Reach
- Sand bed and banks
- Longitudinal slope less than .0003
- Moderate valley confinement within bluffs
- River channel confined by urban and agricultural encroachment
- Land use predominately urban with some agriculture (row crops)

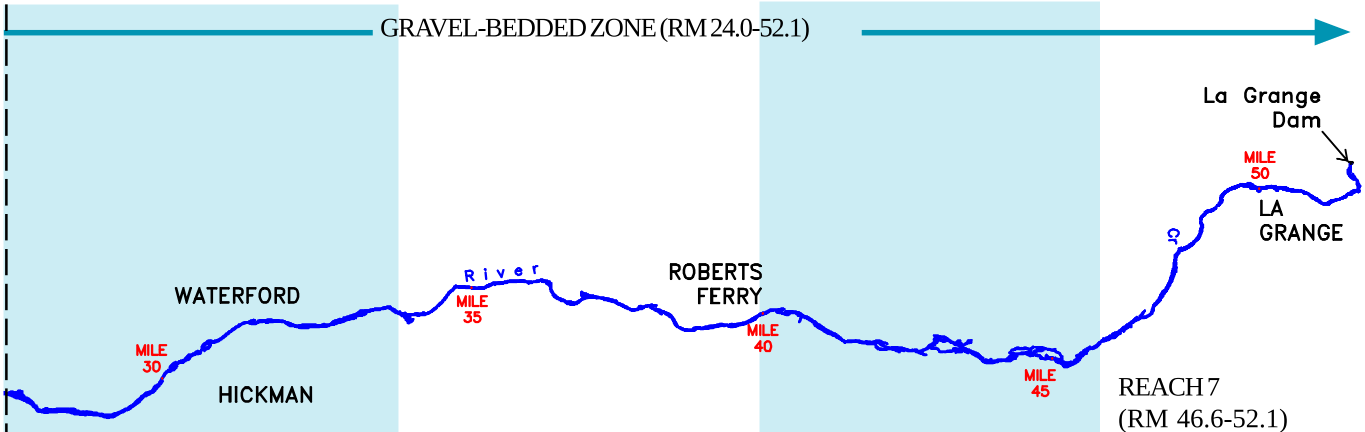
REACH 3
(RM 19.3-24.0)

Upper Sand-bedded Reach
- Sand bed and banks
- Longitudinal slope less than .0003
- Little valley confinement within bluffs
- River corridor confined by agricultural encroachment
- Land use predominately agriculture (row crops) with some rural encroachment

Figure 2-14. Tuolumne River geomorphic reach delineation.

2.2.3. Channel morphology (cross section and planform)

Prior to flow and sediment regulation, the Tuolumne River downstream of La Grange behaved alluvially; the channelbed and banks were composed of alluvium (gravel, cobble, boulders), and the flow regime and sediment supply were adequate to form and maintain the bed and bank morphology. Variability in hydrologic and geological controls (e.g., valley width, location and elevation of underlying bedrock) created variable and complex local channel morphologies. As described in the hydrology section, streamflows within a given year and between years varied from as low as 100 cfs in summer months to peak winter floods exceeding 100,000 cfs. The valley walls confined the river corridor to as narrow as 500 ft near Waterford (RM 32.0), whereas reaches downstream of Modesto were virtually unconfined. Bedrock grade control upstream of Modesto also varied, with exposed bedrock formations near the water surface in some locations, and over 50 feet below the riverbed in other locations. These



REACH 4 (RM 24.0-34.2)

In-Channel Gravel Mining Reach
- Gravel bed and banks
- Longitudinal slope between .0003 and .0015
- Little valley confinement within bluffs
- River corridor confined by agricultural encroachment
- Land use predominately off-channel aggregate extraction and agriculture (orchards)
- Extensive history of in-channel aggregate extraction

REACH 5 (RM 34.2-40.3)

Gravel Mining Reach
- Gravel bed and banks
- Longitudinal slope between .0010 and .0015
- Moderate to little valley confinement within bluffs
- River corridor confined by agricultural encroachment and dikes separating river from off-channel mining pits
- Land use predominately off-channel aggregate extraction and agriculture (orchards and row crops)

REACH 6 (RM 40.3-46.6)

Dredger Tailing Reach
- Gravel bed and banks
- Longitudinal slope between .0010 and .0015
- Little valley confinement within bluffs
- River corridor confined by riparian encroachment
- Land use predominately agriculture (livestock grazing)
- Remnant dredger tailings from historic gold mining, some of which was removed for New Don Pedro Project construction

REACH 7
(RM 46.6-52.1)

Dominant Spawning Reach
- Gravel bed and banks
- Longitudinal slope between .0010 and .0015
- Little valley confinement within bluffs
- River corridor confined by riparian encroachment
- Land use predominately agriculture (livestock grazing)
- Remnant dredger tailings from historic gold mining, most of which was removed for New Don Pedro Project construction

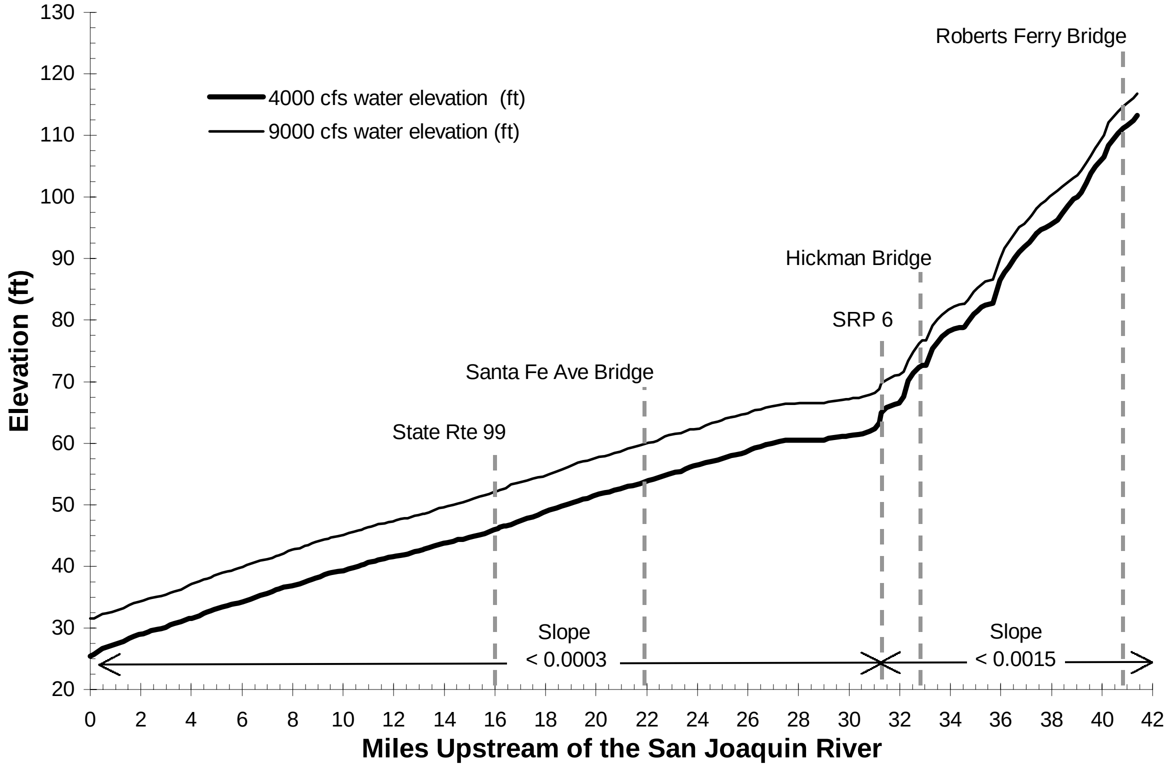


Figure 2-15. Tuolumne River water surface profile generated by the 1969 USGS channel capacity study. Note that the distance are from the floodway length, not the low water channel length, thus differ from commonly used river mileage markers.

factors combined to produce a variable, dynamic, and complex channel morphology. However, *within this local variability, consistent morphological patterns emerge that can be related to habitat requirements of aquatic organisms, and therefore used to formulate restoration objectives.* This interplay between local variability (complexity), general planform, and cross-sectional pattern is extremely important to habitat structure.

There is limited information describing the natural channel morphology of the Tuolumne River prior to the arrival of European settlers. While Native Americans did occupy the Tuolumne River watershed, their interactions with the river had much less impact than actions initiated in the late 1840's with the California Gold Rush. The best characterization of the historical channel morphology would therefore come prior to 1848, but no information exists from this era. The 1854 plat maps, accompanying survey notes, verbal accounts, and lithographs contained in the "History of Stanislaus County" (Branch 1881) provide some glimpse of channel morphology. However, our first documented characterization of the river corridor comes from Soil Conservation Service's 1937 aerial photographs. Considerable gold mining, grazing, and agricultural encroachment had already occurred for many years prior to this photographic series. The main difference between channel conditions observed in 1937 photographs and conditions in later years is that flow regulation and storage in the upstream watershed was more recent, and the landscape had therefore not been appreciably disturbed by flow and sediment regulation. Much of the analysis of natural channel conditions relies on the 1937 photographs.

The fundamental building block of alluvial rivers is the alternate bar unit (Dietrich 1987), composed of an aggradational lobe (depositional feature) and scour hole (the "pool") (Figure 2-16). The submerged portion of the aggradational lobe is commonly called the "riffle", whereas the exposed portion is labeled the "point bar"

(Dietrich 1987). With the relatively deep pool opposite the point bar, this alternate bar unit is analogous to a riffle-pool sequence. An alternate bar sequence, comprised of two point bar units, forms a complete channel meander with a wavelength roughly equaling 9 to 11 bankfull channel widths (Leopold et al. 1964). The structural complexity provided by an alternate bar sequence is extremely important to aquatic organisms in the Tuolumne River, which will be described later in this chapter.

The idealized alternate bar sequence shown in Figure 2-16 is more common in the sand-bedded reach than the gravel bedded reach. Several examples of sinusoidal meanders are evident in the sand-bedded zone (Figure 2-17), with the best example between RM 22 and 24 (Figure 2-18). Less stereotypical alternate bar sequences are common in the gravel bedded reach, and are more complex (Figure 2-19). Common to all manifestation of these alternate bar sequences are several important components:

- During low flows, the channel thalweg meanders around exposed alternating point bars, but during high flows, the bars submerge and the flow direction straightens. Bedload transport during high flows occurs mostly across the bar face rather than along the thalweg (Figure 2-16) (Dietrich 1987).
- There is a transition from exposed, coarser alluvium in the active channel (shaded lighter on Figures 2-17 to 2-19) to finer grained sand and silts on floodplain surfaces.
- Pools are usually found on the outside of meanders; riffles join two adjacent point bars and is the area where flowing water crosses the path of sediment transport (crossover).
- The back sides of point bars often exhibit scour channels, termed lateral scour channels, that provide habitat for numerous species, including salmon.

Historically:

- Channel migration and/or avulsions left remnant alternate bar sequences isolated from the new channel location during low flows (Figures 2-17 to 2-19). This mobile channel created sloughs and oxbows, most of which had standing water from groundwater seepage, and were the focal point of large riparian forests.
- Channel migration, while eroding alluvium on the outside of the bend, deposited new alluvium on the inside of the bend, creating new point bars and floodplains.
- Years with low flows and small floods encouraged riparian vegetation to initiate on bar surfaces, but larger floods that caused point bar scour and channel migration discouraged riparian vegetation from becoming permanently established on the margins of point bars. Therefore, much of the channel margin was gently sloping into the low water channel and relatively free of riparian vegetation.

2.2.3.1. Historical channel morphology in gravel-bedded zone

Prior to flow regulation, large floods, bedload transport, and channel migration resulted in a dynamic channel morphology and diverse riparian vegetation. This dynamic quasi-equilibrium in channel form is characteristic of alluvial rivers (Schumm 1977; Knighton 1984). Bar surfaces had sparse but diverse riparian vegetation, with denser forests concentrated on sloughs, abandoned channel locations, and higher elevation terraces (Figure 2-19). Bankfull channel widths were approximately 550 ft, identified from floodplain indicators on the 1937 aerial photos. A cross section surveyed in 1990 (Trinity Associates) located approximately four miles upstream of Waterford (RM 35.5) shows a clearly defined bankfull channel and floodplain surface that has become fossilized (i.e., unaltered from its past condition by recent geomorphic activity) (Figure 2-20). Using this bankfull indicator, a surveyed water surface slope of 0.0015, and an estimated Manning's roughness value of 0.035 to 0.040 for bankfull flow, the predicted bankfull discharge was 10,000 cfs to 11,000 cfs. This flow equated to a recurrence interval of 1.65 year flood at the La Grange gaging station, which compares favorably with literature values for bankfull discharge (approximately a 1.5 year flood (Leopold 1994), and substantiates our interpretation of this feature as the pre-NDPP bankfull channel. By comparison, the 1.5- year recurrence interval flood for unimpaired conditions determined by flood frequency analysis was 8,400 cfs, thus corroborating field measurements. The bankfull width on this cross section is approximately 540 ft.

Meander wavelengths in the gravel-bedded reach were variable, with typical values near 2,800 feet,

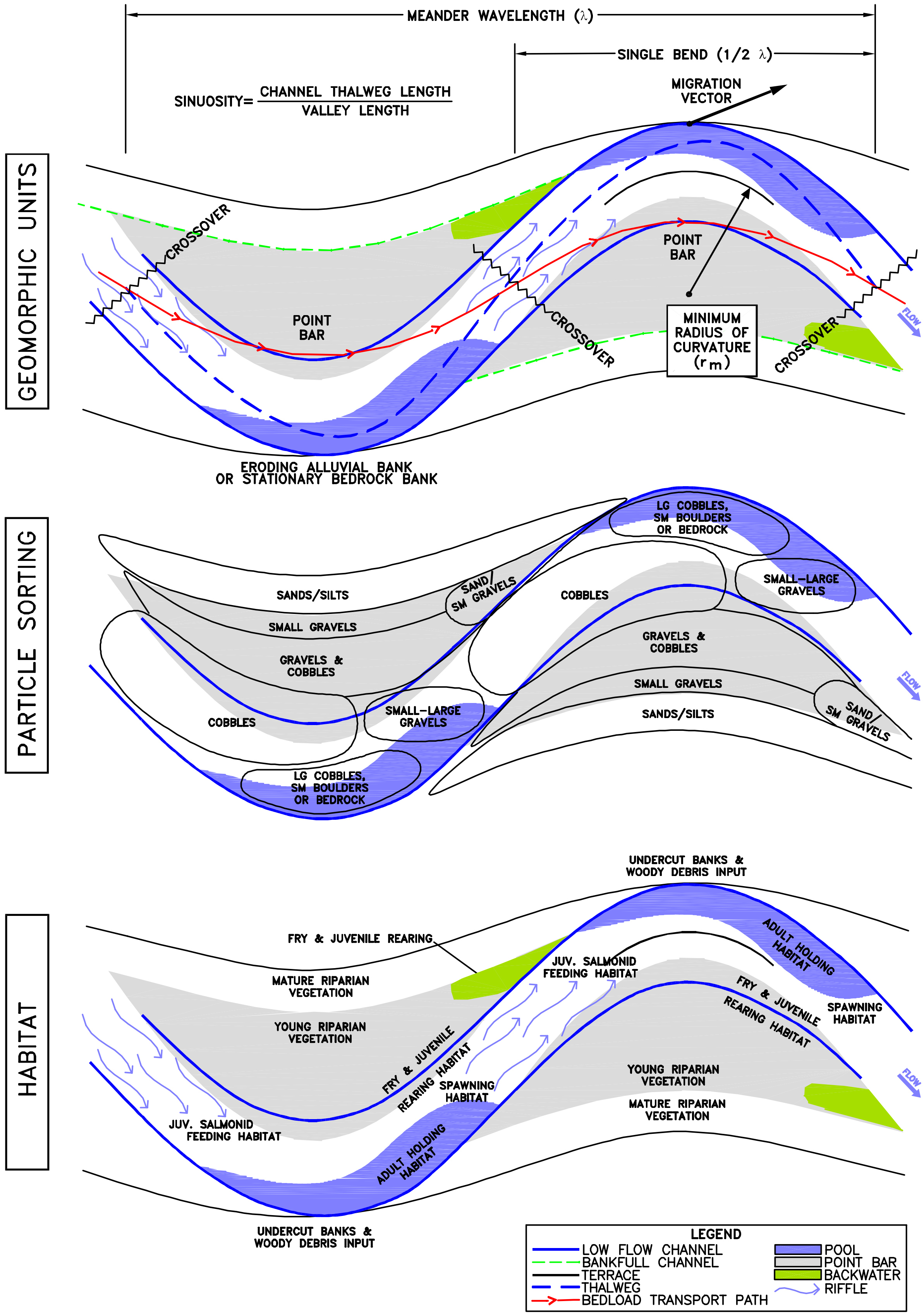


Figure 2-16. Idealized alternate bar unit, modified from Dietrich (1987) and McBain and Trush (1997)

but occasionally reaching as long as 4,000 ft. Meanders typically had low amplitude (< 400 ft) and large radius of curvature (>1,500 ft), and the channel form was a combination of single-thread and split channels (mild braiding) (Figure 2-19). Channel movement appears to have been dominated by a combination of channel avulsion and channel migration.

2.2.3.2. Historical channel morphology in sand-bedded zone

The sharp transition from gravel-bedded to sand-bedded river downstream of Geer Road (RM 24) caused a notable shift in channel morphology: in the sand-bedded zone the channel was almost entirely single thread, and alternate bars approached the idealized pattern (Figure 2-18). Bankfull widths estimated from the 1937 air photos were approximately 600 ft. Meander wavelengths were much less variable than in the gravel-bedded zone, tending toward 3,000 ft. The amplitude of meanders was much higher than the gravel-bedded zone, ranging from 600 ft near RM 23 to 750 ft near present-day Shiloh Bridge (RM 3.5). Channel movement in this zone appears typical of Midwestern sand-bedded streams (e.g., Mississippi River), where progressive channel migration increased meander amplitude and sinuosity until the meander “pinched off” or “cut off”, abandoning most of the meander and re-initiating the migrational pattern. This meander cutoff process created oxbow wetland and riparian habitats that are typically highly productive areas for many species. The lower sand-bedded section of the Tuolumne River is of great potential value as a richly diverse and highly productive area to fish and wildlife production.

2.2.3.3. Historical sediment supply and transport

Sediment comprising the bed and banks of the lower Tuolumne River originated in the Sierra Nevada, and was transported downstream to the Central Valley by winter and spring snowmelt floods. Floods transported a wide range of particles, from cobbles and boulders that formed the structure of gravel bars, to fine sands and silts that formed fertile floodplains. As slope decreased from the Sierra Nevada toward the confluence with the San Joaquin River, particle size decreased from cobbles and boulders near La Grange (RM 50) to fine sand downstream of Dry Creek confluence (RM 16). Specific rates of historic sediment transport were less important than the process itself: *the critical process for the alluvial river reaches, including both sand- and gravel-bedded zones, was that sediment scoured and transported downstream from a particular location was replaced by sediment originating from similar processes upstream.* This functional “conveyor-belt” periodically transported sediment, scoured and rebuilt alluvial deposits, and over time, maintained equilibrium in the quantity and quality of in-channel storage deposits throughout the river. This process in turn provided a consistent renewal and maintenance of high quality aquatic and terrestrial habitat in the lower river.

2.2.3.4. Evolution to present-day conditions

Beginning with the California Gold Rush in 1848 and continuing to the present, Anglo-European manipulation of the channel morphology has caused large-scale changes to the Tuolumne River corridor (Table 2-6).

After more than a century of cumulative impacts, the river has been transformed from a dynamic, alluvial river (capable of forming its own bed and bank morphology) to a river fossilized between either man-made dikes, or agricultural fields, or fossilized within riparian vegetation that has encroached into the low water channel. Riparian forests have been reduced in areal extent, and natural regenerative processes have been inhibited. Excavation of stored bed material for gold and aggregate mining eliminated active floodplains and terraces and left behind large in-channel and off-channel pits. Off-channel pits are separated from the river by steep-banked dikes and dikes which confine the channel to an unnaturally narrow corridor. The loss of coarse sediment supply that historically provided essential sediment for the formation of alternate bar features and in-channel and floodplain habitat structure, combined with the dramatic reduction in high flows, has prevented regenerative fluvial processes from promoting river recovery. These changes are largely responsible for the currently degraded state of the river channel. Not only are the ingredients for a healthy channel no longer available to the river (sediment supply), but the processes are handicapped or absent (high flow regime and natural variability within hydrograph components).

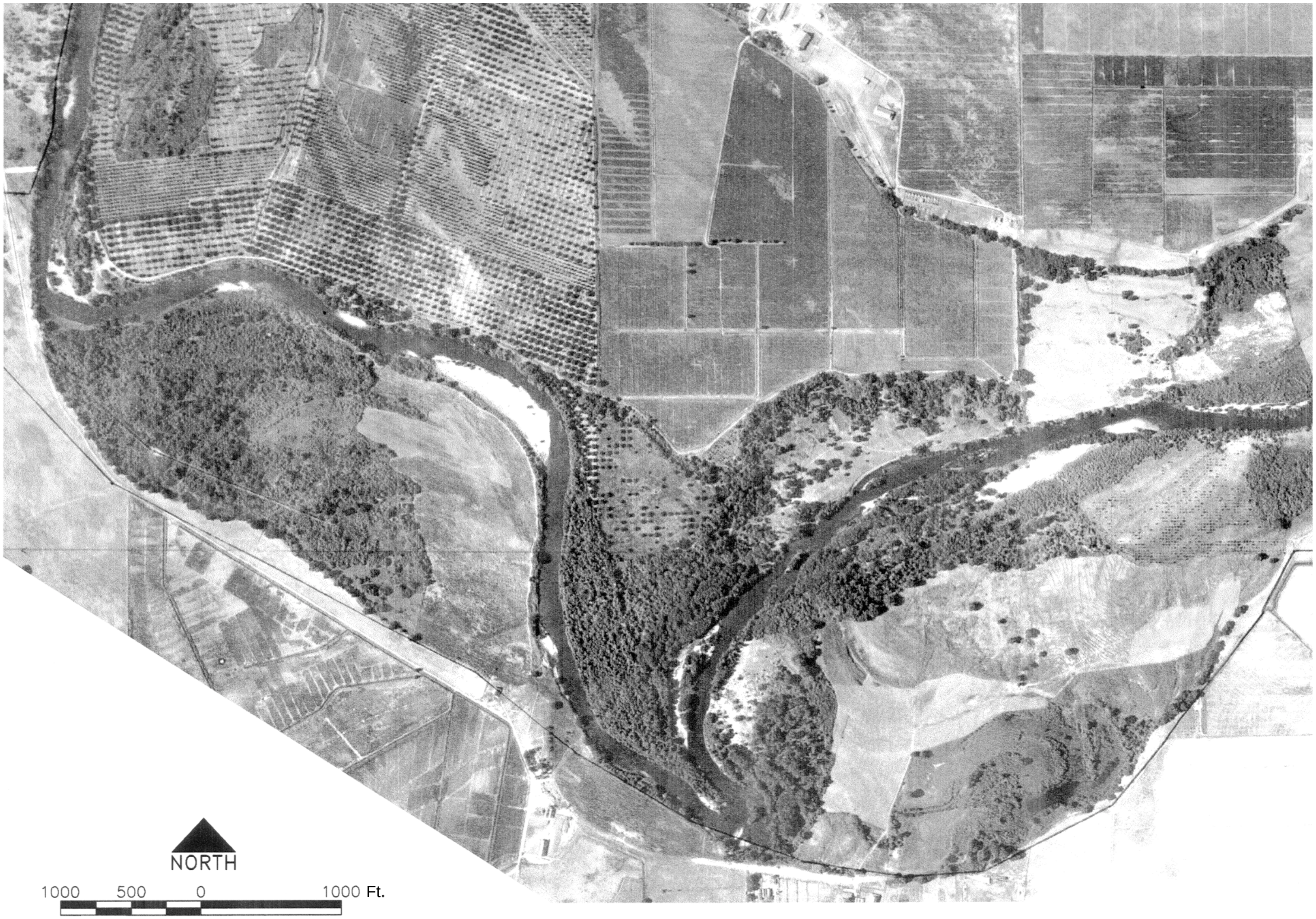


Figure 2-17. 1937 example alternate bar sequence in sand-bedded reach near the San Joaquin River confluence (RM 4.5), showing a rapidly migrating alternate bar morphology and large tracts of riparian vegetation. Note conversion of riparian vegetation to agricultural use is well underway.

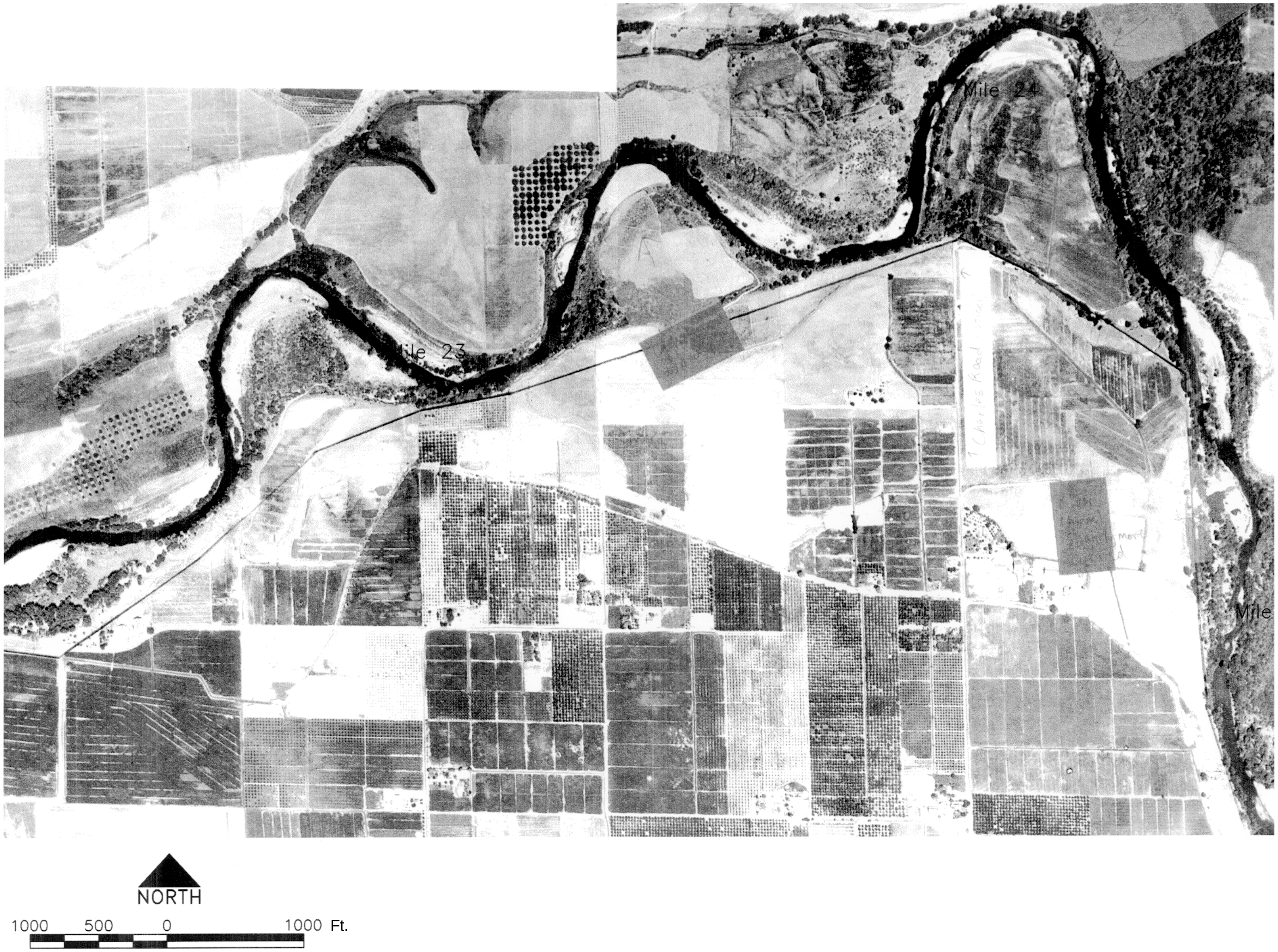


Figure 2-18. 1937 example alternate bar sequence in sand-bedded reach immediately downstream of the gravel-to-sand bedded transition (RM 23), showing more consistent alternate bar morphology.

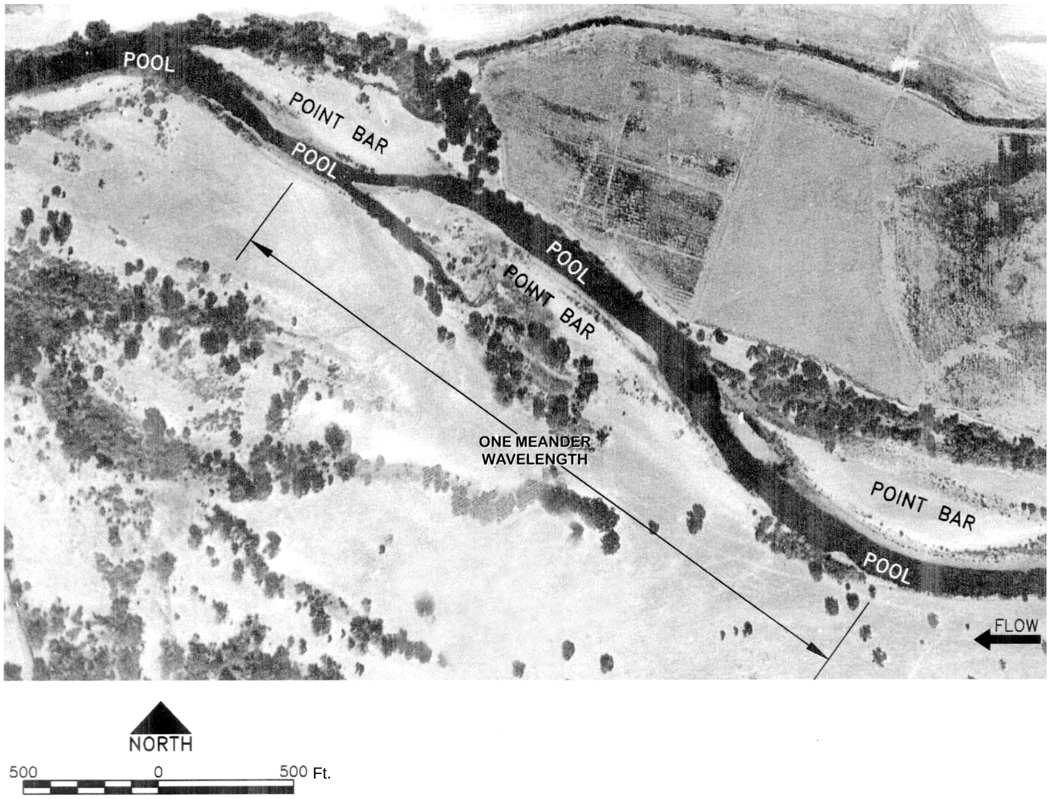


Figure 2-19. 1937 example alternate bar sequence in gravel-bedded reach, near 7/11 Materials plant site at RM 38.

The effects of these changes are illustrated by comparing 1937 photos with 1993 photos. In the gravel-bedded zone, the impact of aggregate extraction is well illustrated: historic floodplains were mined to depths far below the river thalweg, and the resultant pits are separated from the river by dikes constructed of either gravel or topsoil (Figure 2-21). In downstream reaches from RM 35.0 to 24.0, in-channel aggregate extraction pits within the low water channel range up to 38 ft deep and 400 ft wide. Reduction in the magnitude of flood-peaks has caused the low water channel location to remain nearly constant over time. The previously dynamic channel and point bar on the north bank in Figure 2-21, and elsewhere, have not changed since 1937 and have rarely been mobilized since 1970 as a result of the reduced high flow regime. Leading edges of point bars that were previously free of mature vegetaton, are now encroached by a thick band of willows, buttonbush, and alders. In upstream reaches where dredgers operated across the valley, the unnatural and fragmented channel location has not changed appreciably since 1937 (Figure 2-22).

Changes to the sand-bedded reaches are similar, but resulted from agricultural and urban encroachment rather than aggregate extraction. Conversion of the riparian corridor to agriculture and urban uses reduced floodway width, and introduced bank protection that functionally halted channel migration (compare Figures 2-17 and 2-18 to Figures 2-23 and 2-24). Reduced peak flows also inhibit channel migration.

2.3. ATTRIBUTES OF ALLUVIAL RIVER ECOSYSTEM INTEGRITY

Although the ecological integrity of the Tuolumne River has suffered, there is considerable opportunity to improve the river corridor by re-establishing critical fluvial geomorphic processes. But defining, let alone restoring, a riverine ecosystem is challenging. We hypothesize that the fundamental Attributes of river ecosystem integrity are defined by the physical processes that create and maintain the ecosystem form or physical structure. Based on our interpretation of historical conditions on the Tuolumne River (assumed to approach undisturbed conditions), and literature documentation of natural fluvial processes in other alluvial rivers, we developed a list of “Attributes of Alluvial River Ecosystem Integrity.” This approach was useful in developing quantitative rehabilitation objectives on the Trinity River in Northern California (McBain and Trush 1997), which can be applied to the Tuolumne River. Restoring these critical Attributes, within boundaries defined by societal constraints, is essential for improving the health and productivity of the Tuolumne River. Because the river behaves differently between the gravel-bedded zone and the sand-bedded zone, several Attributes are unique to each reach.

ATTRIBUTES OF ALLUVIAL RIVER ECOSYSTEM INTEGRITY

ATTRIBUTE No. 1. Spatially complex channel morphology.

No single segment of channelbed provides habitat for all species, but the sum of channel segments provides high-quality habitat for native species. A wide range of structurally complex physical environments supports diverse and productive biological communities;

ATTRIBUTE No. 2. Streamflows and water quality are predictably variable.

Inter-annual and seasonal flow regimes are broadly predictable, but specific flow magnitudes, timing, durations, and frequencies are unpredictable due to runoff patterns produced by storms and droughts. Seasonal water quality characteristics, especially water temperature, turbidity, and suspended sediment concentration, are similar to regional unregulated rivers and fluctuate seasonally. This temporal “predictable unpredictability” is a foundation of river ecosystem integrity;

ATTRIBUTE No. 3. Frequently mobilized channelbed surface.

In gravel-bedded reaches, channelbed framework particles of coarse alluvial surfaces are mobilized by the bankfull discharge, which on average occurs every 1-2 years. In sand-bedded reaches, bed particles are in transport much of the year, creating migrating channel-bed “dunes” and shifting sand bars.

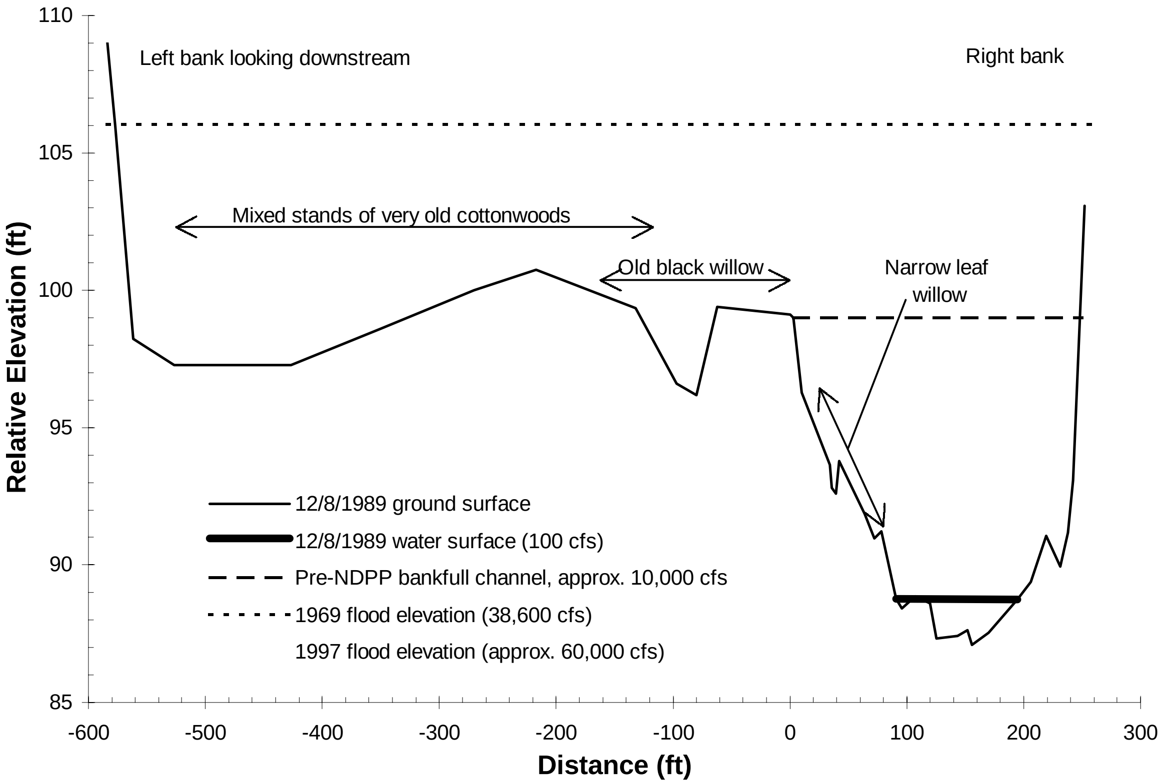


Figure 2-20. Cross section at RM 35.5 showing fossilized pre-NDPP bankfull channel and floodplain surface in gravel-bedded reach.

ATTRIBUTE No. 4. Periodic channelbed scour and fill.

Alternate bars are scoured deeper than their coarse surface layers by floods exceeding 3- to 5-year annual maximum flood recurrences. This scour is typically accompanied by re-deposition, such that net change in channelbed topography following a scouring flood usually is minimal. In gravel-bedded reaches, scour was most likely common in reaches where high flows were confined by valley walls;

ATTRIBUTE No. 5. Balanced fine and coarse sediment budgets.

River reaches export fine and coarse sediment at rates approximately equal to sediment inputs. The amount and mode of sediment storage within a given river reach fluctuates, but sustains channel morphology in dynamic quasi-equilibrium when averaged over many years. A balanced coarse sediment budget implies bedload continuity: most particle sizes of the channelbed must be transported through the river reach;

Table 2-6. Land uses and effects on the lower Tuolumne River from 1848 to present.

Land Use	Time Period	Location	Disturbance	Effect on channel
Placer Mining	1848-1880	La Grange and Upstream (RM 50)	Turned over floodplains and terraces; spoil placement on fertile areas	Destroyed natural channel morphology, increased sediment supply, destroyed instream habitat, removed riparian forests
Urban Growth	1850-present	Modesto to Waterford (RM 15 to 30)	Need for commercial lumber, space and aesthetic value	Confined river corridor (reduced width), constructed dikes, removed riparian vegetation, increased pollution loading into river
Dredger Mining	1880-1952	Roberts Ferry to La Grange (RM 38 to 50)	Turned over entire riparian corridor valley-wall to valley-wall; spoil placement on fertile areas	Destroyed natural channel morphology, increased sediment supply, destroyed instream habitat, removed riparian habitat
Grazing	1850-present	San Joaquin confluence to La Grange (RM 0 to 50)	Young riparian vegetation is grazed, water sources become feces conduits	Destabilized banks, discouraged natural riparian regeneration
Farming	1860-present	San Joaquin confluence to La Grange (RM 0 to 50)	Mature and establishing riparian vegetation is cleared. Channel location stabilized	Confined river corridor (reduced width), constructed dikes, removed riparian vegetation, increased pollution and fine sediment loading into river
Flow Regulation	1890-present	Downstream of La Grange (RM 0 to 52)	Magnitude, duration, frequency, and timing of high flow regime is altered and reduced, reduced/eliminated sediment supply from upstream watershed	Bed coarsening and downcutting, fine sediments accumulated in channel, channel fossilized by encroaching riparian vegetation, channel migration and bar building virtually eliminated, floodplain construction and deposition reduced, quantity and quality of instream and riparian habitat greatly reduced
Aggregate Mining	1930-present	Hughson to La Grange (RM 24 to 50)	Large instream and off channel pits, dredger tailing removal	Historic floodplains are left as deep ponds, floodway narrowed by dikes separating ponds from river, riparian vegetation is cleared, regeneration is prevented and mature stands eliminated.

Figure 2-21. 1993 example alternate bar sequence in gravel-bedded reach, near 7/11 Materials plant site at RM 38, showing aggregate extraction on historic floodplain surfaces and confinement of contemporary floodway with dikes and encroached riparian vegetation. Compare to Figure 2-19.

ATTRIBUTE No. 6. Periodic channel migration and/or avulsion.

The channel migrates at variable rates and establishes meander wavelengths consistent with regional rivers with similar flow regimes, valley slopes, confinement, sediment supply, and sediment caliber. In gravel-bedded reaches, channel relocation can also occur by avulsion, where the channel moves from one location to another, leaving much of the abandoned channel morphology intact. In sand-bedded reaches, meanders decrease their radius of curvature over time, and are eventually bisected, leaving oxbows;

ATTRIBUTE No. 7. A functional floodplain.

On average, floodplains are inundated once annually by high flows equaling or exceeding bankfull stage. Lower terraces are inundated by less frequent floods, with their expected inundation frequencies dependent on norms exhibited by similar, but unregulated river channels. These floods also deposit finer sediment onto the floodplain and low terraces;

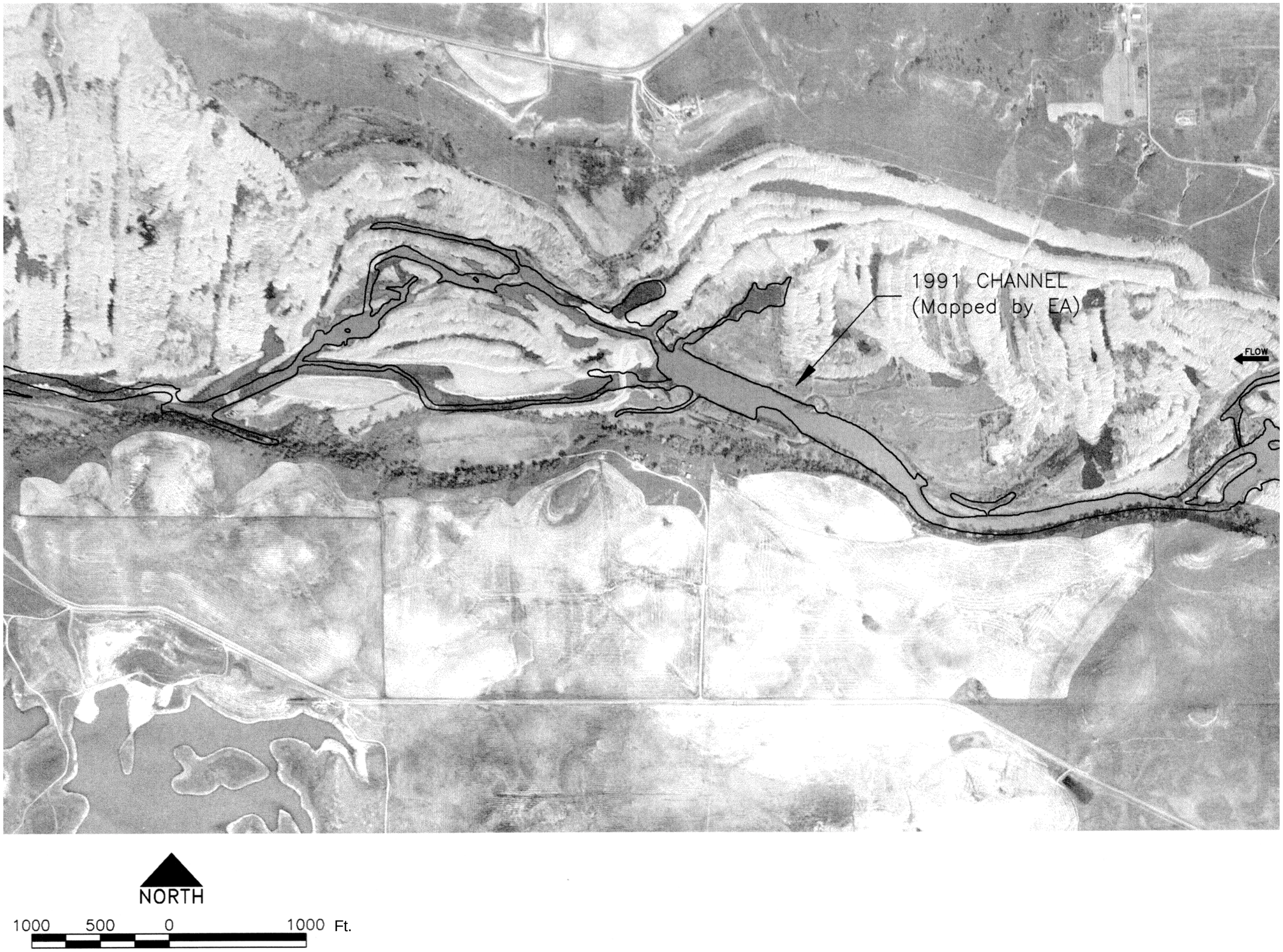


Figure 2-22. 1950 photo of dredger tailings upstream of Roberts Ferry (RM 43), showing that the channel location has not appreciably changed from 1950 to 1993.

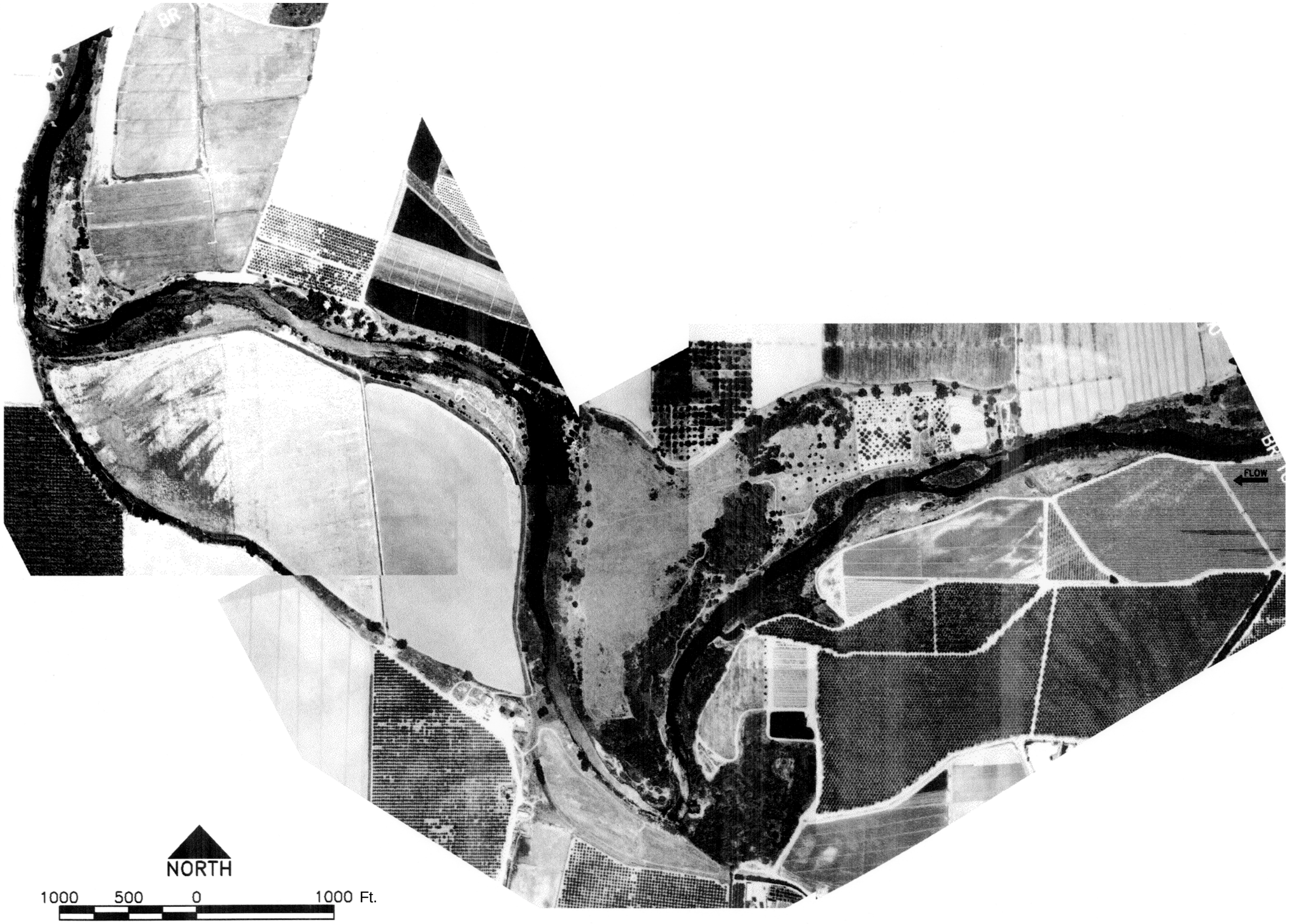


Figure 2-23. 1993 example alternate bar sequence in sand-bedded reach near the San Joaquin River confluence (RM 4.5), showing agricultural encroachment, loss of floodplain, and loss of riparian corridor. Compare to Figure 2-17.

Figure 2-24. 1993 example alternate bar sequence in sand-bedded reach immediately downstream of the gravel-to-sand bedded transition (RM 23), showing agricultural and urban encroachment on point bars. Compare to Figure 2-18.

ATTRIBUTE No. 8. Infrequent channel resetting floods.

Single large floods (e.g., exceeding 10-yr to 20-yr recurrences) cause channel avulsions, rejuvenate mature riparian stands to early-successional stages, form and maintain side channels, and create off-channel wetlands (e.g., oxbows). Resetting floods are as essential for creating and maintaining channel complexity as lesser magnitude floods, but occur less frequently;

ATTRIBUTE No. 9. Self-sustaining diverse riparian plant communities.

Based on species life history strategies and inundation patterns, initiation, maturation, and mortality of native woody riparian plants culminate in early- and late-successional stand structures and species diversities (canopy and understory) characteristic of self-sustaining riparian communities common to regional unregulated river corridors;

ATTRIBUTE No. 10. Naturally-fluctuating groundwater table.

Groundwater tables within the floodway are hydrologically connected to the river, and fluctuate on an inter-annual and seasonal basis with river flows. Groundwater and soil moisture on floodplains, terraces, sloughs, and adjacent wetlands are supported by this hydrologic connectivity.

Attribute number 2 (variable flow regime) is central to all physical and ecological processes, thus causes many of the other attributes. The need to emphasize annual flow variation warrants this distinction as a separate attribute. The usefulness of all Attributes is derived by their ability to define desired conditions and quantifiable channel rehabilitation goals. Attribute No. 9 is the only "biological" attribute, and is included because of the interactions of hydrologic and fluvial processes with riparian vegetation.

The biological benefits of these geomorphically-based restoration actions are discussed in the following sections.

2.4. BIOLOGICAL RESOURCES

2.4.1 Riparian resources

A discussion of riparian vegetation within the Tuolumne River corridor must be premised on the biological and physical processes that perpetuate riparian vegetation. The term "riparian" describes a unique physical environment and associated plant vegetation along banks of freshwater bodies, watercourses, estuaries, and surface-emergent aquifers and adjacent areas. Streamflows and groundwater in these areas provides soil moisture sufficiently in excess of that available through local precipitation, rendering these areas capable of supporting vegetation that requires moderate amounts of water (Warner et al. 1984). *The extent of groundwater influence therefore defines the riparian corridor width and the plant assemblages that grow there*.

California riparian corridors are uniquely dominated by winter deciduous hardwood trees, which can only survive within the microclimatic and edaphic (soil and soil moisture) conditions within the riparian corridor (Robichaux 1977). Riparian vegetation patterns and species common today are remnant of the last ice age, in which higher precipitation supported these plants in upland habitats as well as along river bottoms. During the last 15,000 years, what we know as riparian vegetation in the Central Valley has become restricted to river corridors, and now grows only within the approximate 100-year flood limits (Katibah 1984). The interaction between plant species and the physical environment creates spatially complex, heterogeneous vegetation assemblages.

The complexity and heterogeneity of riparian vegetation renders their classification cumbersome; in the past, the predominant classification schemes were "communities" and "associations." However, the term "community" has not been universally defined, implies artificial boundaries and interactions (e.g., that each community is independent of adjacent communities), and also includes animal populations . "Associations" assume that certain species associate with each other, within site-specific conditions, and often cannot be expanded to other locations.

To avoid problems associated with these classification systems, the Restoration Plan uses the "plant series" classification system based on Sawyer and Keeler-Wolf (1995). This system accommodates the natural patchiness along the Tuolumne River. Plant series consist of repeating patches of vegetation, usually comprised of multiple species, but always having one or two species that dominate. Series are stratified into canopy, shrub, and ground layers, with the series name determined by the species of greatest relative abundance within the highest strata (Sawyer and Keeler-Wolf 1995). The list of plant species comprising the stand defines the composition of a particular plant series.

Individual riparian plant species typically have four life-cycle stages: initiation, establishment, maturity, and senescence (Figure 2-25). These stages are defined as follows:

1. Initiation begins after a seed lands on exposed, moist substrate and germinates; this stage continues through the first growing season.
2. Establishment begins after the first growing season and continues until the plant has enough resources to begin sexual reproduction.
3. Maturity begins when a plant first flowers and produces seeds.
4. Senescence follows maturity, when seed production and reproductive capacity decline.

The morphology of riparian stands is a result of hydrologic, climatic, and fluvial processes interacting with the life history of individual species. Over time, these processes vary mortality rates at each life stage, resulting in variable and dynamic riparian stands. For example, a particular year may exhibit high seedling mortality associated with a high flow scouring flood, while later, more moderate floods may encourage seedling survival on certain bank surfaces.

2.4.1.1 Fluvial processes and riparian life-history

Riparian stands of the pre-1850 Tuolumne River corridor were created and maintained by complex interactions between the physiologic tolerances of each plant species and the dominant physical processes, which includes:

- <u>hydrologic</u>: magnitude and timing of flow inundation, and groundwater table fluctuation;
- <u>fluvial geomorphic</u>: channel morphology (scour channels, sloughs, floodplain/terrace elevations), channel migration and avulsion, fine sediment deposition on floodplains and terraces, point bar scour, and woody debris transport.

<u>Hydrological processes</u>

Annual streamflow patterns and riparian plant lifecycles interact to produce a dynamic relationship between (1) mortality caused by surface or groundwater inundation or dessication and (2) survival when adequate soil moisture conditions correspond to seed availability. High flows that exceed the bankfull stage inundate floodplains and recharge groundwater tables in floodplains, oxbow lakes, and sloughs. Historically, the timing of spring snowmelt floods coincided with seed-release timing of most woody riparian species (May-July), so when floodplain, oxbow, and slough surfaces were moist, airborne seeds landed and germinated on these surfaces. Point bar surfaces, generally at lower elevations than floodplains, were inundated during seed dispersal, which prevented germination.

Occasionally, long duration spring snowmelt floods had deleterious effects on certain riparian plants. Plants typically breath through their roots, but when roots are underwater they become deprived of oxygen, causing considerable stress to the plant. Plants respond to inundation, cold temperatures, and short photo period by going into dormancy. This increases their survival. Fremont cottonwood and white alder have evolved pores in their bark called lenticels, which increase gas exchange to the plant during long-term inundation, increasing their resistance. Fremont cottonwoods and white alders tend to break dormancy earlier than willows, and this longer growth period benefit gives them an advantage over willows. Under natural conditions, the longer growing season for cottonwoods and alders, combined with willows being more susceptible to scour mortality because they typically grow closer to the main channel, resulted in a more equal distribution of species. Loss of winter scouring floods and long-duration inundation snowmelt floods has favored willow species (particularly narrow-leaf willow) and reduced natural regeneration of cottonwoods, reducing riparian species diversity and complexity.

Spring snowmelt floods rose and fell gradually. After the peak, river water levels declined gradually through summer months (Figures 2-4 to 2-8, and 2-10). In some years oxbow lakes and sloughs dried up completely, requiring plant roots to follow receding moisture down into the soil column. Some plant species evolved rapidly growing roots to follow the dwindling sub-surface soil moisture (Segelquist et al. 1993). During summer months, soil moisture gradients caused by varying elevations relative to the groundwater table created strong selective pressures on vegetation. These gradients, combined with local soil differences, caused distinctive zonation patterns in riparian

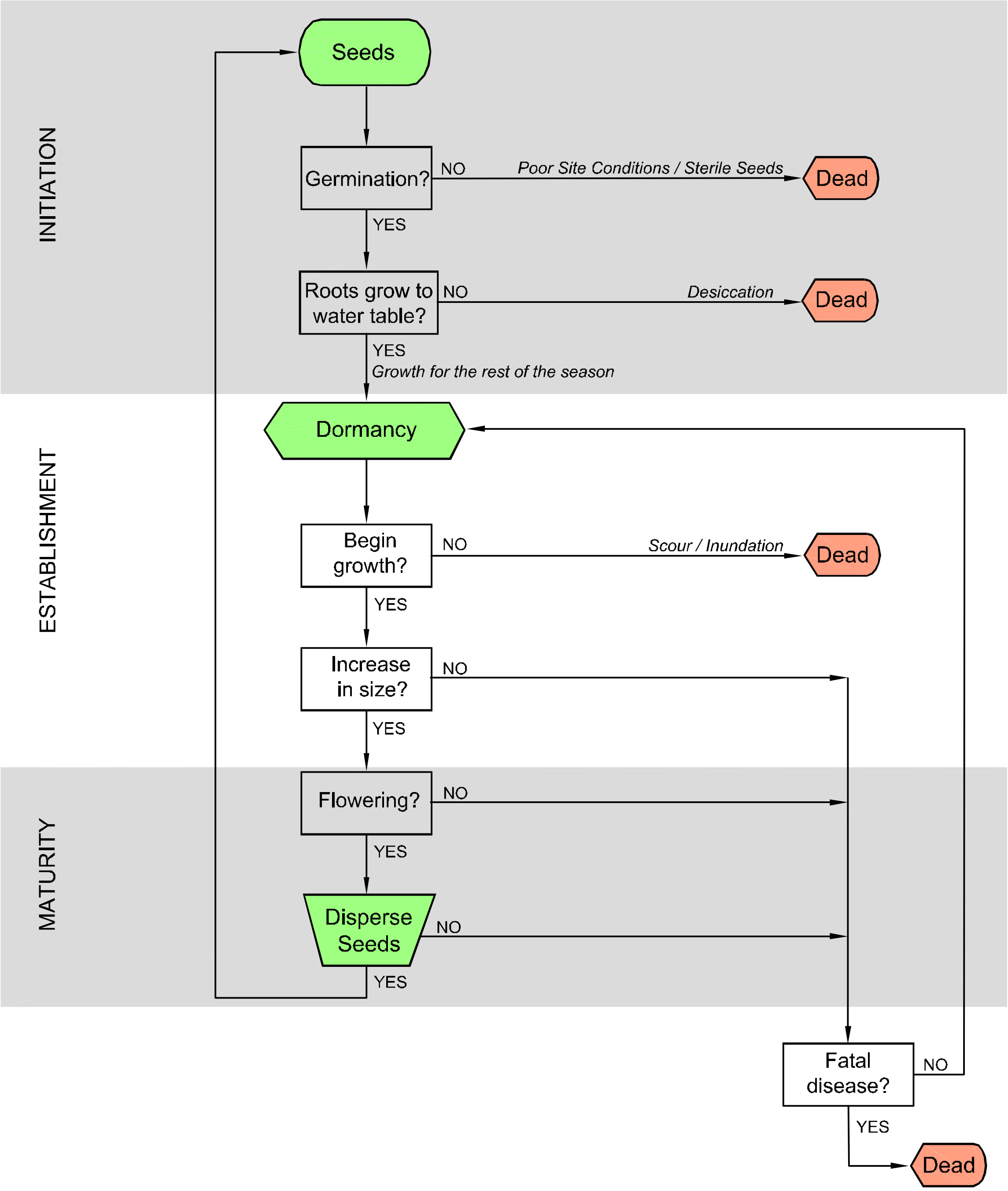


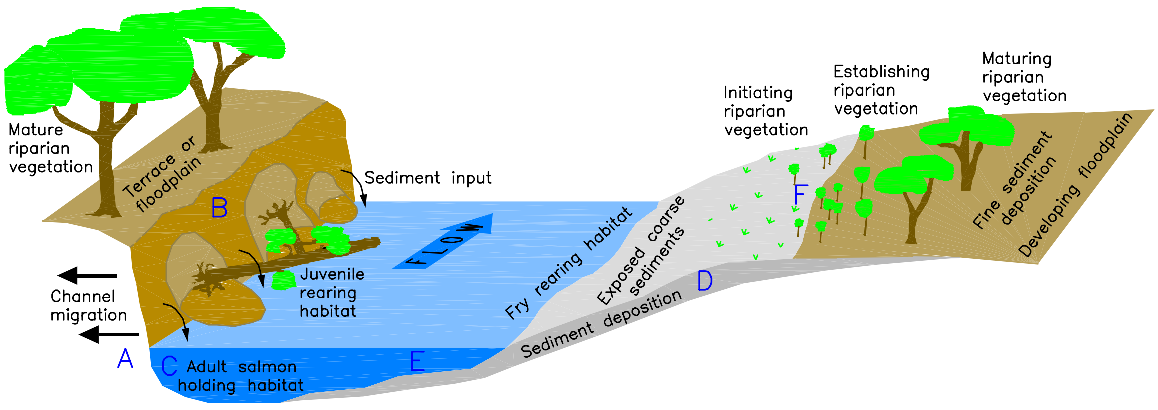
Figure 2-25. A generalized riparian hardwood life cycle showing life stage, and mortality agents that affect life stages.

vegetation. In many locations, plants initiated but were later unable to survive because of insufficient soil moisture. Desiccation mortality may prevent initiation for many successive years, causing distinct age classes between successful riparian stand cohorts.

Fluvial geomorphic processes

Channel migration and avulsion are typically considered undesirable because migration often results in damage or loss to human structures. However, channel migration (Attribute #6) was a critical process for riparian regeneration and large woody debris introduction into the channel. Alluvial channels typically migrate across the river valley by eroding the outside of the meander bend and undercutting mature riparian forests. This process historically introduced woody debris, which added structural complexity to instream habitat (Figure 2-26). Additionally, bank erosion on the outside of the bend was balanced by bar deposition and floodplain formation on the inside of the bend (Figure 2-26). Fine sediments deposited on the inside of the bend are ideal seed beds, and if hydrological conditions provide adequate moisture, new initiating bands of riparian vegetation advance along the building bar. This process is best illustrated historically in the sand-bedded reaches, where scroll bars of finer sediments caused banding of emergent riparian vegetation on the inside of meander bends (Figure 2-17). In the gravel-bedded reaches, substrates were coarser and drained better. Consequently, riparian forests were historically much more extensive in the lower river.

In sand-bedded reaches, large floods typically spread out over the valley and did not cause large-scale and rapid change in channel location; rather, meander evolution and eventual cutoff were the primary avulsion processes. These meander-bend cutoffs usually left either sloughs or oxbow lakes, and because they initially provided clean seed bed surfaces and constantly moist condition, riparian regeneration (Figure 2-27) quickly occured there.



An example of the dynamics of natural rivers is depicted above. (A) A channel with adequate space to migrate (Attribute 6) erodes the channel bank on the outside of the meander bend during high flows (Attribute 2), (B) encouraging aged riparian trees to topple into the channel (Attribute 9). (C) A deep pool also forms here, which provides structural complexity (Attribute 1) for good fish habitat. As bank erosion continues, the pool "migrates" downstream (Attribute 6), but high quality habitat is maintained. (D) On the opposite bank, high flows (Attribute 2) scour and redeposit coarse sediments (Attributes 4 and 5), forming a shallow bar on the inside of the meander bend (Attribute 1), and providing clean spawning gravels. (E) This area, in turn, provides ideal slow-water rearing conditions for juvenile chinook salmon, as well as habitat for aquatic insects (fish food), amphibians and reptiles. (F) Progressively higher up the gravel bar surface, a dynamic interplay occurs between receding water levels during the spring snowmelt (Attribute 2), and the presence of riparian tree seeds (Attribute 7). These woody riparian trees are sporadically scoured out (Attribute 8), and those established high enough on the bank are toppled into the channel as the channel migrates back across the valley (A).

Figure 2-26. Conceptual role of channel migration in creating spatially and temporally complex riparian corridor habitat.

Figure 2-27. 1937 photo at the confluence of the San Joaquin River, showing oxbows and scroll-bars, bank erosion, and the range of riparian age classes. Undisturbed floodplains and low terraces supported lush riparian forests. Note conversion of riparian vegetation to agricultural use is well underway.

In gravel-bedded reaches, channel avulsion and floodplain disturbance typically occurred during large floods (>5 to 10-year recurrences on the annual maximum series). Channel relocation appears to have been rapid, perhaps occurring in many locations within a single flood event. Additionally, larger floods scoured and re-deposited sediment around trees, logs, and shrubs on floodplains and low terraces, which created sloping, undulating, floodplain surfaces. This floodplain morphology led to considerable variation in soil and drainage conditions, and provided diverse plant species (each with different physiological tolerances) a broad range of microhabitats in which to survive (Strahan 1984).

However, these larger floods also caused mortality to the riparian community, primarily in the steeper, more confined gravel-bedded reach. Typically, the closer to the low water channel a riparian plant initiated, the higher the risk of scour mortality. Conversely, the farther from the low water channel, the higher the risk of desiccation mortality. Channelbed scouring floods historically prevented riparian hardwood encroachment into the active channel and kept point bars relatively free of riparian vegetation (Figures 2-17 to 2-19). Seedlings initiating close to the summer low water edge have shallow roots and are particularly susceptible to channelbed surface scour, and moderate winter flood events typically kill over 90% of the plants that survive the first growing season (McBain and Trush 1997).

Floods caused scour mortality not only on young generations of trees, but also on mature and senescent trees. As floods progressively inundated floodplain surfaces with greater depths, woody debris in transport would accumulate on mature and senescent stands with force great enough to topple trees. In some cases, a group of trees may have been removed in a domino effect, leaving bare holes in a stand where new initiation could occur. Historically, the large volume of woody debris derived from the upper watershed prior to dam blockage would have had significant effects on riparian stand structure.

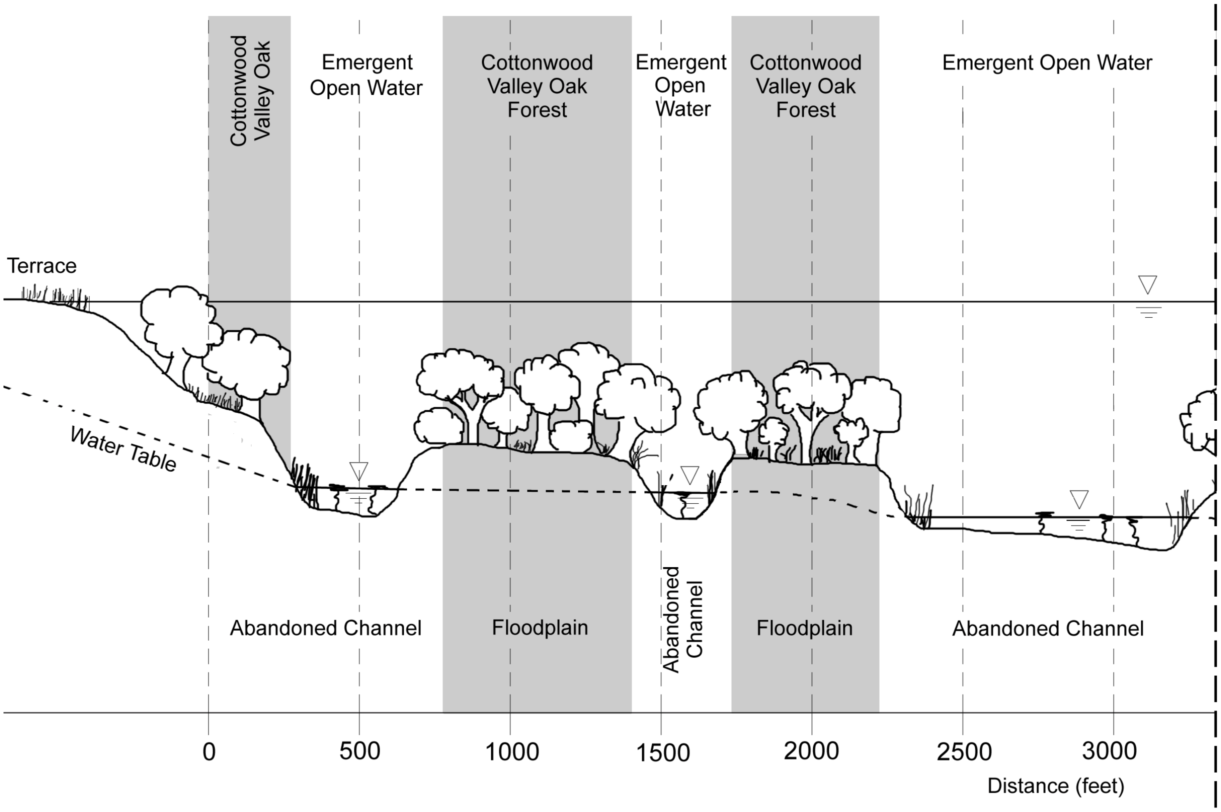


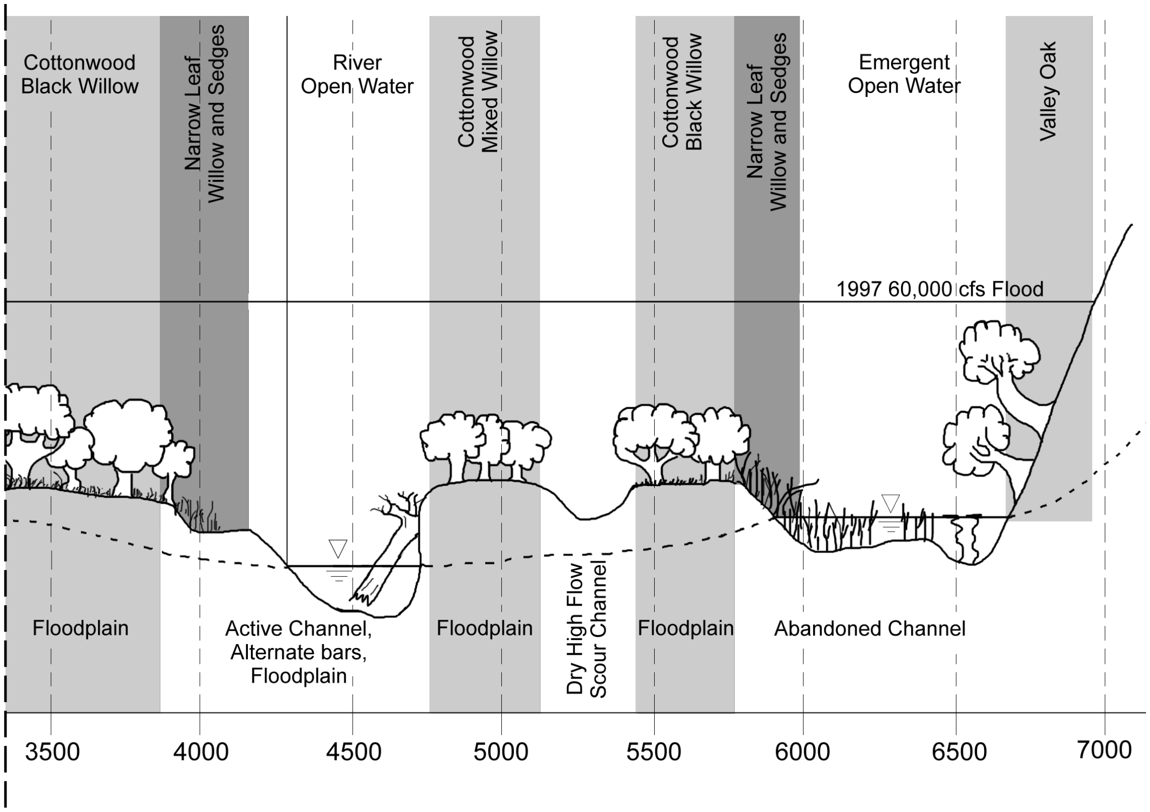
Figure 2-28. Conceptual historical cross-section near Shiloh Bridge (RM 3.5). Riparian vegetation occurs across entire cross section, and is concentrated in oxbows (historic channel locations) and scour channels. Note tree size not to scale.

Large floods also deposited considerable volumes of fine sediment on floodplains, and less frequently on terraces, creating seed beds that encouraged riparian initiation. New fine sediment deposits imported nutrients, improving plant growth and regeneration on floodplain and terraces. Again, initiation success also depended on local soil moisture conditions. To avoid suffocation from deep silt and sand deposited at the base of established plants, many species developed the ability to sprout adventitious roots further up the trunk, closer to the new depositional surface, to preserve gas exchange functions.

Each woody riparian species and life stage responds differently to hydrologic and fluvial processes, but particular plant life stages are more vulnerable to the effects of flow variation and fluvial processes. Initiating and early establishing plants are especially susceptible to mortality agents because substrate composition and water availability are vital during early life stages. If they survive the summer, they are susceptible to scour-induced mortality during relatively small winter and spring floods. Once the plant escapes a two to four year window and develops deeper and more extensive root system, the risk of mortality decreases. Ultimately, mortality to maturing plants depends on channel migration, being pushed over by flood debris, or disease. These periodic and spatially variable disturbance patterns and mortality agents perpetuate the plant series diversity historically found along the Tuolumne River.

2.4.1.2. Pre-settlement riparian vegetation composition

Prior to the gold rush era, the riparian corridor extended miles wide in places where the river lacked confinement. Pre-settlement riparian vegetation in the sand-bedded reaches was comparable to a lush jungle “gallery forest” where lianas (vines) connected the canopy to dense undergrowth (Bakker 1984) (Figures 2-17, 2-27, 2-28). Throughout the corridor, western sycamore, Fremont cottonwood, Oregon ash, and



valley oaks grew in profusion on floodplains and terraces, while willows and alders grew along active channel margins. In mature riparian stands, clematis, grape, and poison oak lianas draped from the canopy to the ground. An estimated 13,000 acres of riparian vegetation occupied the Lower Tuolumne River from La Grange to Modesto (RM 19-52) before widespread European settlement in the 1850's (Katibah 1984). In gravel-bedded reaches, relatively sparse riparian vegetation was restricted between bluffs, and flourished in high flow scour channels and abandoned main channels where soil moisture conditions were optimal and flood effects were minimal (Figure 2-19).

Diversity in plant series and stand structure was maintained by the dynamic interaction between initiation and maturation on one hand, and mortality on the other. Dominance of one species over another was kept in check by variable mortality agents provided by dynamic hydrologic and fluvial processes. This struggle between plant physiological tolerances and fluvial and hydrologic processes resulted in noticeable patterns in species location on specific geomorphic surfaces. Riparian plants have been shown to initiate and establish after floods of specific recurrence intervals (Bradley and Smith 1984; Osterkamp and Hupp 1984; Auble et al. 1994). The riparian inventory (presented in Chapter 4) and cross sections through riparian vegetation (Figure 2-20) suggest that these relationships historically existed on the Tuolumne River (Table 2-7).

2.4.1.3. Impacts of land use on riparian vegetation

At present, less than 15% of the historical riparian forests remain along the Tuolumne River. Human alteration of riparian vegetation began with Native American harvest and fire management, but human manipulation intensified with placer gold mining in the late 1800s, followed by dredge mining, flow and sediment regulation, urban encroachment, agricultural encroachment, grazing, and aggregate extraction (Table 2-6). Mining activities and urban/agricultural encroachment directly removed large tracts of riparian vegetation (compare Figures 2-17 to 2-19 with Figures 2-21 to 2-24); other land uses were less direct. For example, livestock selectively graze younger riparian plants, which severely limits riparian initiation.

Flow and sediment regulation indirectly impacted riparian vegetation on the Tuolumne River by modifying the hydrologic and fluvial processes that influence survival and mortality of riparian vegetation. Each increment of flow regulation (La Grange Dam, Hetch Hetchy Dam, Old Don Pedro Dam, New Don Pedro Dam) successively reduced the magnitude, duration, and frequency of flood flows, and removed key mortality agents (scour, channel migration, flood toppling, and inundation). Reduced flood scour allowed riparian vegetation to initiate along the low water channel, where historically they would have been scoured out. As vegetation matured, extensive root systems anchored alluvial deposits to functionally fossilize historically dynamic alluvial features. This process has been documented on rivers with large upstream storage reservoirs (Pelzman 1973), and is commonly referred to as riparian encroachment.

Prior to flow regulation, riparian vegetation periodically encroached onto active channel surfaces (e.g., during drought), but large floods eventually scoured these geomorphic surfaces, causing mortality to much of the encroached vegetation. Large storage reservoirs eliminated

Table 2-7. Rlationships between established riparian plant series, flood frequency, and streamflow for the lower Tuolumne River corridor based on cross section surveys and GIS analysis.

Plant Series	Recurrence Interval range	Pre-NDPP Magnitudes (cfs)	Post-NDPP Magnitudes (cfs)
Narrow-leaf willow	summer baseflow to 1.5 year flood	150 to 8,500	150to 3,020
White alder/ Box elder	1.5 year to 5 year flood	8,500 to 25,000	3,020 to 7,500
Fremont Cottonwood	5 year to 20 year flood	25,000 to 51,000	7,500 to 12,800
Valley oak	20 year to the 100 year flood	51,000 to 89,000	12,800 to 18,000

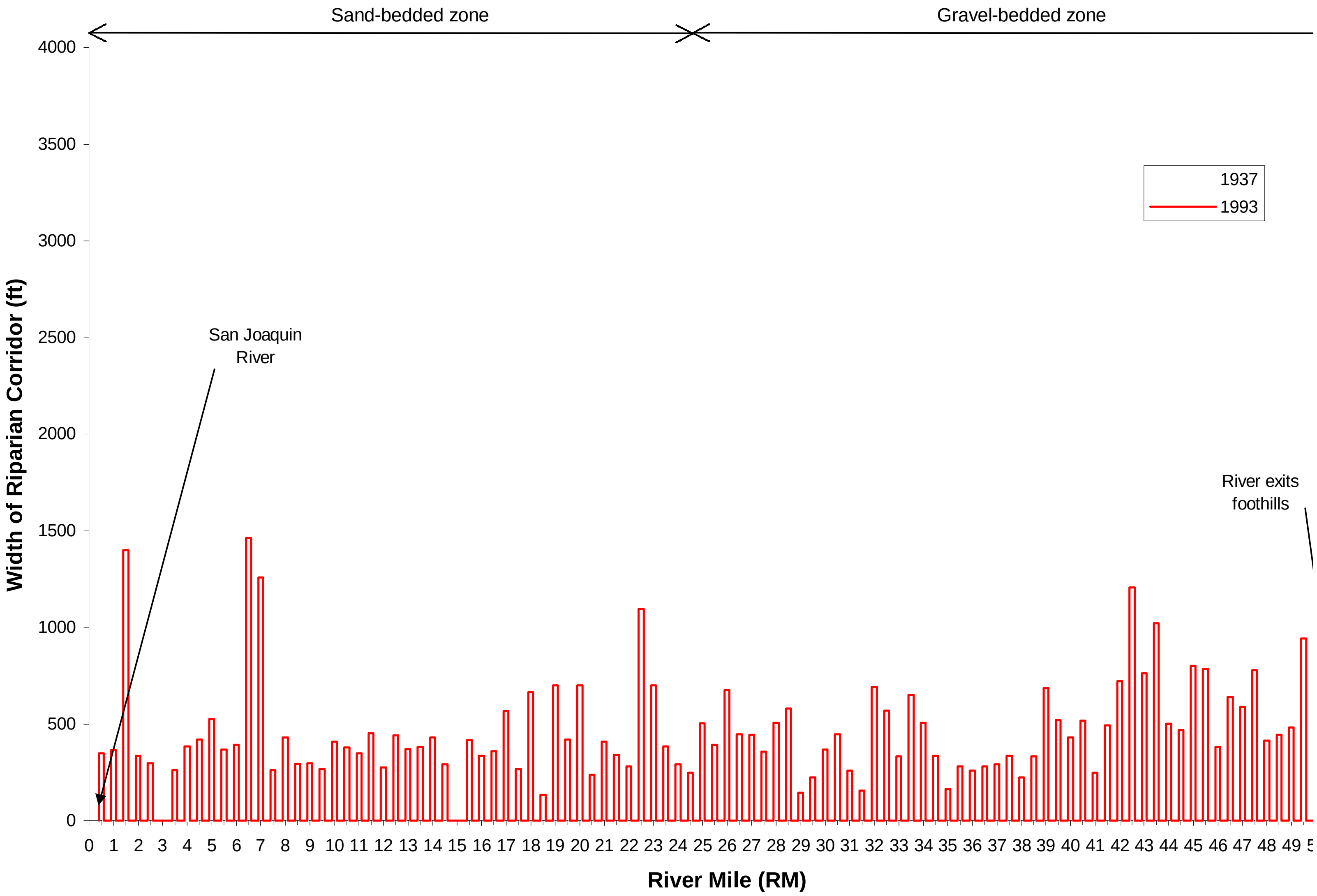


Figure 2-29. Riparian corridor widths in 1937 and 1993, starting at the Tuolumne River's confluence with the San Joaquin River (RM 0.0) and ending just upstream of the New La Grange Bridge (RM 51.5).

large floods, allowing encroached riparian stands to mature and senesce, forming uniformly aged stands. Additionally, when larger floods do occur, the minimal loading of woody debris is insufficient to topple trees. Lastly, because dams functionally trap all sediment from the upper watershed, flood flow releases scour away rather than deposit fine sediment (fine sands and silt), thus discouraging vegetation initiation on contemporary surfaces.

To illustrate changes to the riparian corridor width, we examined 1937 and 1993 aerial photographs to measure the extent of riparian shrub and tree vegetation every half mile, for the entire Tuolumne River corridor (Figure 2-29). Valley width, which defines the historic riparian corridor, was also plotted. By 1937, extensive disturbance had already reduced riparian vegetation to a small fraction of its prior extent, and further reductions between 1937 and 1993. Near the confluence of the Tuolumne River with the San Joaquin River at RM 5.5 (formerly the McClesky Ranch), the 1937 riparian forests on the southern bank exceeded 120 acres; these forests were reduced to 30 acres by 1993. This evolution is illustrated by the conceptual cross sections near Shiloh Bridge (compare Figure 2-28 with 2-30). Channel migration (and woody debris input) has decreased from reduced flows and bank rip-rap. The functional riparian corridor width has also been reduced as farmable land was maximized by “reclaiming” the riparian corridor. Vegetation that once extended from bluff to bluff prior to the gold rush era is now confined to a narrow band (yards wide) along the active

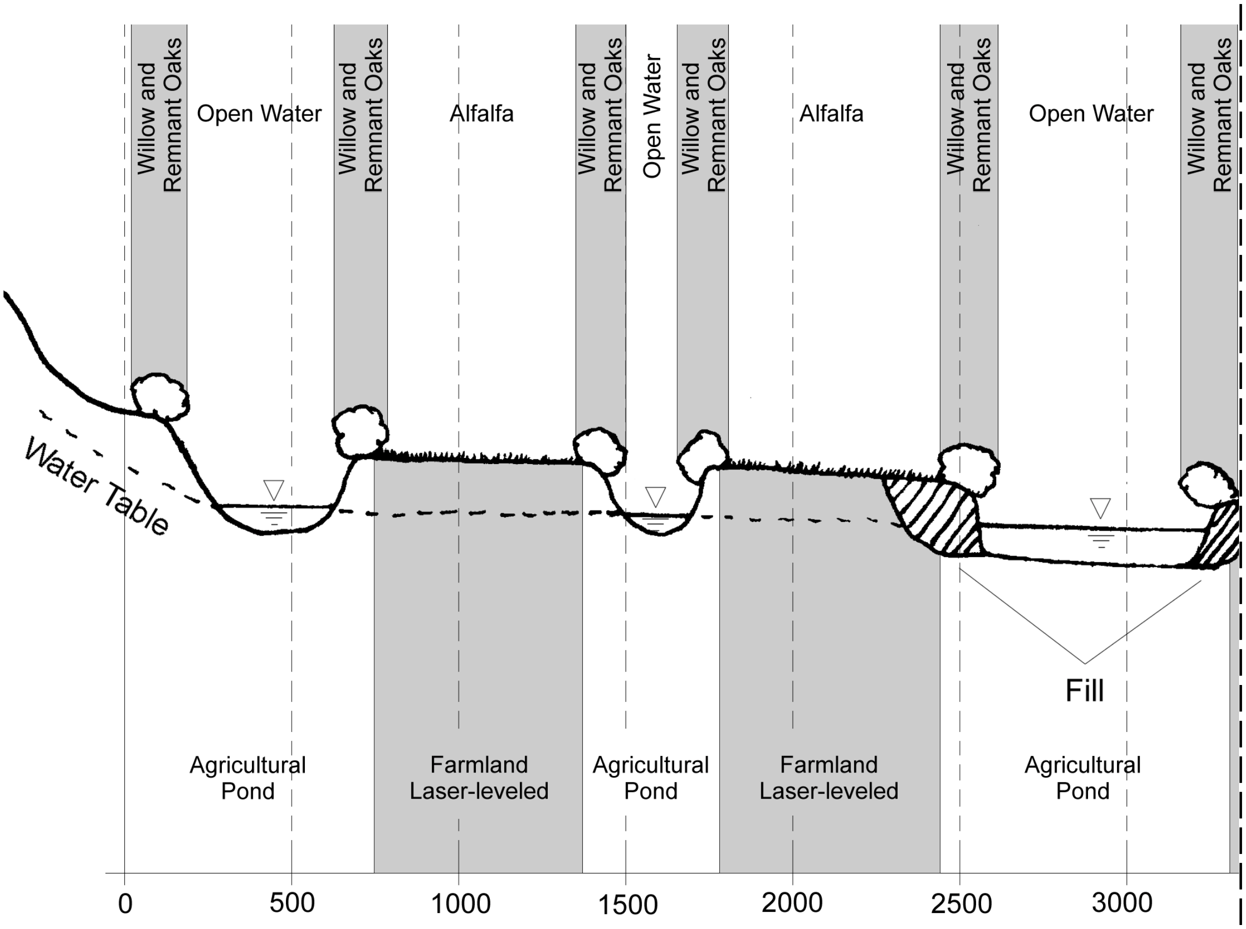


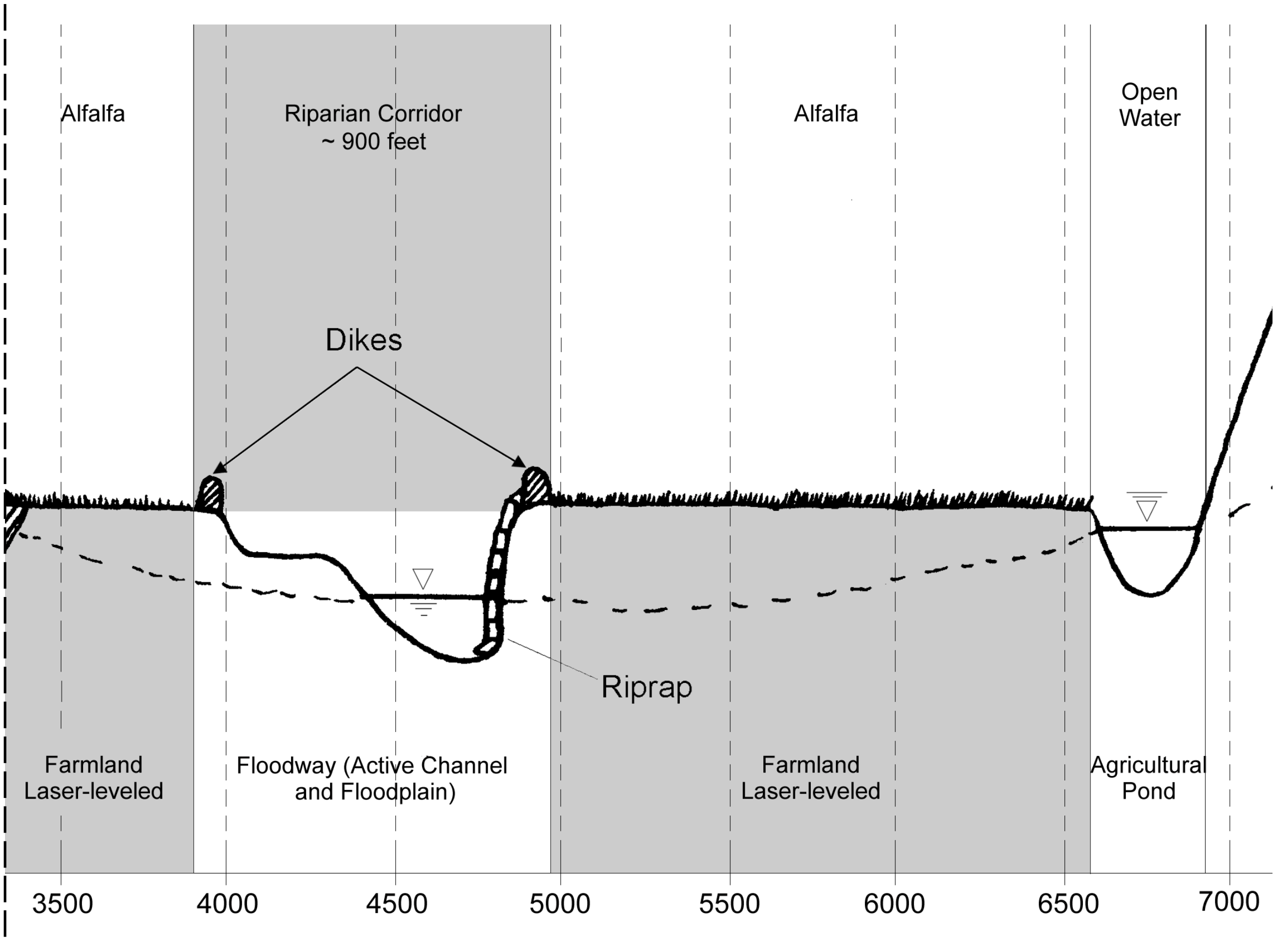
Figure 2-30. Conceptual existing cross-section near Shiloh Bridge (RM 3.5). Riparian vegetation is restricted to a narrow band along the low water margin, and grows on what were open point bars before dam closure in 1971.

channel in many locations (Figure 2-21) or is altogether nonexistent.

Changes to riparian vegetation directly affect microclimate, nutrient availability, habitat quality and diversity (Gregory et al. 1991). Loss of channel migration and clearing of valley oaks and cottonwoods in the riparian corridor decreased large woody debris recruitment, reduced woody plant cover along the river corridor, encouraged exotic plants to infiltrate into the riparian zone, and increased ambient temperatures within the river corridor. In reaches where the riparian zone has been less disturbed, Fremont cottonwood and valley oak stands have become senescent, while younger willow, alder and box elder stands are encroaching along the low flow channel. This evolution has contributed to simplifying the channel morphology. Riparian encroachment has transformed channel margins from shallow, low velocity, exposed cobble habitat (high quality habitat for chinook rearing) to deeper, higher velocity habitat.

2.4.1.4. *Summary of riparian resources*

Past and present land use practices combined with streamflow and sediment regulation transformed the Tuolumne River corridor from an alluvial river system in dynamic quasi-equilibrium, to a semi-static river channel. This transformed environment scarcely resembles ecological conditions to which riparian vegetation, salmonids, and other wildlife species adapted; as a result, riparian habitat area and species diversity has declined dramatically. The following section examines the



relationship between salmon habitat and life history, exploring cause and effect relationships between changes in fluvial processes and salmon population stability.

2.4.2. Chinook salmon

2.4.2.1. Life history

Chinook salmon, *Oncorhynchus tshawytscha*, are the largest of the five North American Pacific salmon species, occasionally weighing over 90 pounds, although most adults weigh from 10 to 40 pounds. Chinook are anadromous and semelparous (die after spawning once), with two behavioral forms: one designated as “stream-type” and the other as “ocean-type” (Healey 1991). Ocean-type chinook are typical of populations on the Pacific coast south of British Columbia, as on the Tuolumne River. In general, ocean types migrate to sea during their first year of life, usually within four months after emerging from the spawning gravels, spend most of their ocean life in coastal waters, and return to their natal river in the fall to spawn. Presently, fall-run chinook salmon constitute the most abundant anadromous run in the Sacramento/San Joaquin River system (Yoshiyama 1998), and support the bulk of ocean harvest.

Most chinook salmon return to spawn in freshwater streams when they are between two and five years old. The two-year-old grilse (precocious males and females that prematurely migrate back into the river) are abundant in some years, but Central Valley runs are now comprised mostly of three-year-olds. Four- and five-year-old fish were once far more common than at present. The gradual decrease in the average age and size of fish in the Central Valley runs is a result of heavy commercial ocean fishing (EA 1992).

The life-cycle of the chinook salmon begins and ends on the spawning grounds (Figure 2-31). In the San Joaquin basin, adults typically arrive at the spawning grounds from October into December, peaking in early to mid November. Spawning takes place from mid October through late December. Duration of incubation varies depending on water temperature, but generally extends for 60-90 days. Alderdice and Velson (1978) report that time to 50 percent hatching ranged from 159 days at 37^{o}F to 32 days at 61^{o}F. Winter water temperatures on the Tuolumne River typically range between 48^{o}F and 60^{o}F. Alevins

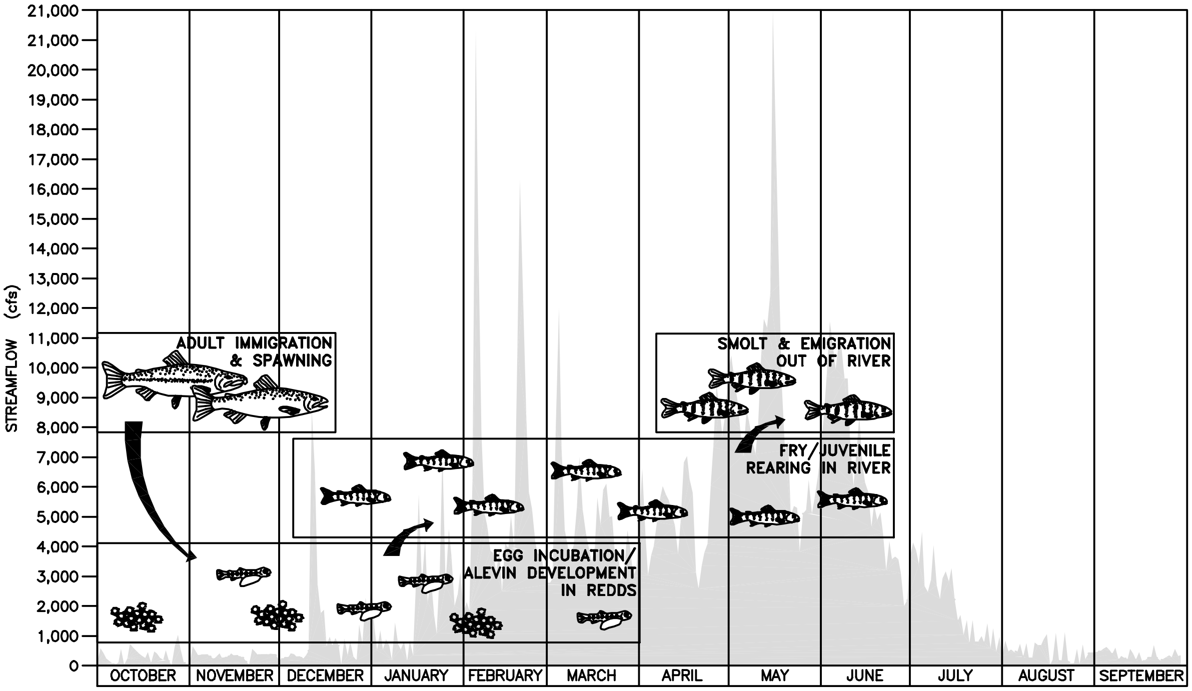


Figure 2-31. Life cycle of the Tuolumne River fall-run chinook salmon, showing how major stages in their life history relate to typical annual runoff patterns. The unimpaired average annual hydrograph for WY 1996 is used as example.

remain in the gravel for two or three weeks after hatching, absorbing most of their yolk sac before emerging as fry into the water column. Fry emerge mostly from January to March.

Fry (length<50 mm) may emigrate from the river into the Bay/Delta estuary soon after emergence, or rear in the river for several months. The later-emigrating juveniles (length>50 mm) generally leave the Tuolumne River in April or May and enter the ocean as smolts between April and July. Hatton and Clark (1942) trapped emigrating fry and juveniles in fyke nets at Mossdale in the San Joaquin delta from 1939-1941. Their data suggest bimodal peaks in emigration, with one peak in February and another in April. Several factors may determine the timing of fry and juvenile migration, and whether fry and juveniles rear in-river or continue downstream. Some researchers suggest that fry migration is related to flow magnitude. Kjelson et al. (1981) observed peak seine catches of chinook fry in the Sacramento/San Joaquin Delta correlated with increases in streamflow from storm runoff. Other authors speculate that social interaction or density-dependent mechanisms cause fry to be displaced downstream (Lister and Walker 1966; Reimers 1968; Major and Mighell 1969). Roper and Scarnecchia (1999) report that timing of smolt emigration was significantly related to stream temperature and phase of the lunar cycle, but not discharge. All of these factors likely interact to play a variable mechanistic role in the downstream distribution of fry from the Tuolumne River, depending on flow, habitat availability and condition, and population density.

A small portion of the chinook salmon juvenile population produced annually may remain to over-summer in the Tuolumne River and then emigrate as yearlings to the ocean in winter or the following spring (EA 1992). This rare, but potentially important, life history strategy on the Tuolumne River is most likely controlled by whether summer/fall water temperatures are suitable for fish survival.

Pacific salmon form local populations with genetic variation maintained by adaptations to environmental conditions (Taylor 1991). Adaptations arise as evolved characteristics of the species that are inherited by each individual from the preceding generations as behavioral, physiological or developmental responses to changing environmental conditions. Adaptive responses modify the behavior or morphology of the organism to improve its relationship to the environment and maximize the survival and fitness of the individual. Considerable adaptive variability in salmonids has apparently evolved since glacial recession within the last 15,000 years (Taylor 1991). Preliminary information from genetic studies on Central Valley chinook salmon indicate differences between seasonal runs but little divergence among fall-run stocks (Nielsen et al. 1994; Banks et al. 1996) However, more comprehensive genetic evaluations are in progress that could reveal possible genetic differences in fall-run chinook salmon from the Tuolumne River and other Central Valley streams.

Environmental conditions to which chinook salmon are adapted include:

- a variable flow regime that inundated different segments of the channelbed with different timing, frequencies, depths, and velocities;
- a structurally and topographically diverse channelbed, providing habitat for various species and life stages at most flows;
- interactions with the biological community that provided invertebrate food resources, and which included competitive or predatory interactions with other fish and wildlife species.

The following sections describe hydrologic conditions, habitat conditions, and community interactions that provided historical environmental conditions within which chinook salmon evolved. Along with an historical context, contemporary conditions are also described, using available data, photo series, and general ecological principles.

2.4.2.2. Constraints limiting production and survival of chinook salmon

Physical alteration of the channel morphology, dams and flow regulation, and elimination of coarse sediment supply have cumulatively degraded chinook salmon habitat in the gravel-bedded reaches. The once dynamic and complex Tuolumne River channel has become static, providing less in-channel, floodplain, and riparian habitat than the historic channel provided (Table 2-8).

In response to the degraded conditions and requirements mandated by the NDPP license, the Districts conducted a multi-year research program

Table 2-8. Major impacts to chinook salmon habitat and population levels resulting from alterations to historical hydrologic and fluvial geomorphic processes.

Changes in hydrology, fluvial geomorphology, or channel morphology	***Impacts to chinook salmon life history or habitat***
Reduced frequency and magnitude of peak flows	Reduced frequency of spawning gravel turnover and cleansing, resulting in reduced survival of eggs and alevins. Riparian fossilization of alluvial deposits and concurrent loss of rearing habitat along margins of point bars. Disruption of immigration/emigration patterns, particularly during juvenile and smolt emigration. Reduced spawning gravel availability.
Reduced baseflows	Higher concentration of pesticides and fertilizers from agricultural return flows. Increased superimposition of redds resulting in significant egg mortality.
Loss of upper watershed areas	Reduced access to spawning and rearing habitats, reducing production potential. Reduced nutrient supply, reducing production potential.
Loss of coarse sediment supply and transport	Reduced spawning habitat quantity and quality. Reduced exposed bars, reducing rearing habitat along lateral bar features. Coarsening of bed surface, reducing spawning habitat quality.
Loss of Large Woody Debris (LWD)	Reduced nutrients supply and habitat structural diversity.
Loss of fine sediment transport capacity	Accumulation of in-channel fine sediment storage reduced adult holding habitat and emergence success. Infiltration of fine sediments into spawning gravels decreases emergence success. Increased imbeddedness of surface particles degrades fry rearing habitat.
In-channel gravel extraction and gold dredger mining	Reduced spawning and rearing habitat area. Increased habitat availability for non-native fish species that prey on juvenile salmon, reducing smolt out migration success. Reduced ability of river to route coarse sediment through reaches, decreasing spawning and rearing habitat.
Off-channel gravel extraction	Confinement of floodway and prevention of channel migration, reducing spawning and rearing habitat. Loss of riparian habitat, floodplain, and gravel recruitment as floodplains are mined and banks are armored.

to assess chinook salmon population dynamics and habitat conditions in the lower Tuolumne River. The study approach attempted to identify potential physical and biological limitations to chinook salmon production, specifically factors that limited salmon production levels (EA 1992). Potential limiting factors (ecological constraints) identified include:

- reduced spawning gravel availability, and egg mortality from superimposition of redds;
- poor spawning gravel quality causing low egg survival-to-emergence;
- inadequate streamflow during fry and juvenile emigration;
- reduced and degraded rearing habitat;
- increased in-river predation by non-native fish species;
- increased Bay/Delta and ocean mortality (striped bass predation, delta pumping mortality, sport/commercial harvest);
- elevated in-river and Bay/Delta water temperatures.

Additional research (CDFG 1998) has also indicated that significant juvenile and smolt mortality may occur in the sand-bedded reaches, potentially related to predation and/or unfavorable water temperatures.

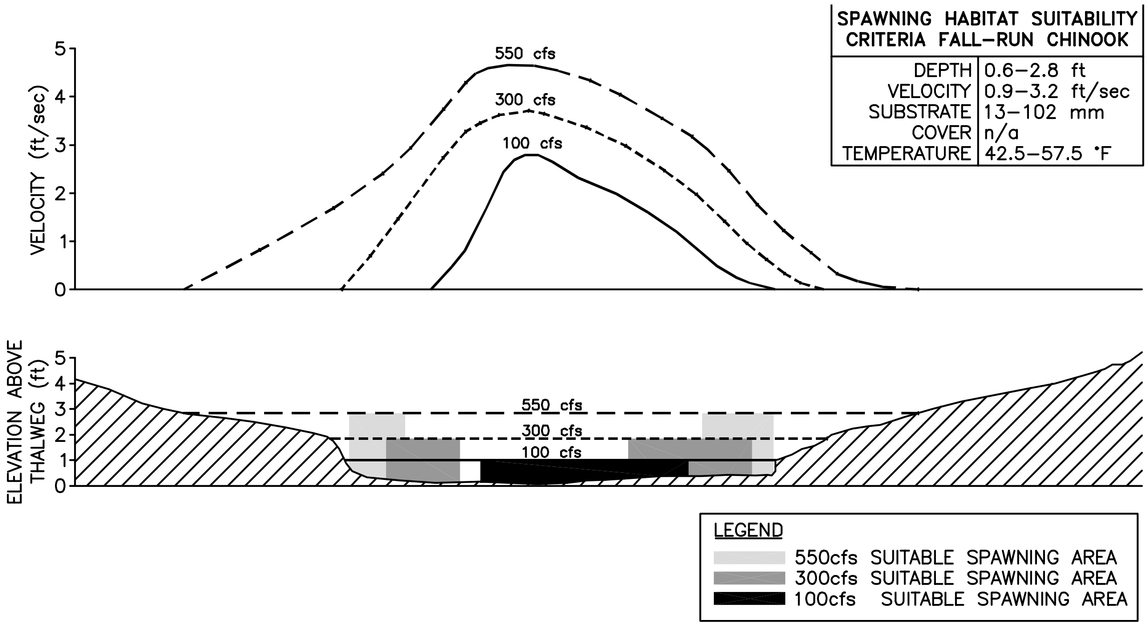


Figure 2-32. Conceptual cross section through a spawning riffle to show the effects of flow variation on distributing spawning area to lateral margins of the channel.

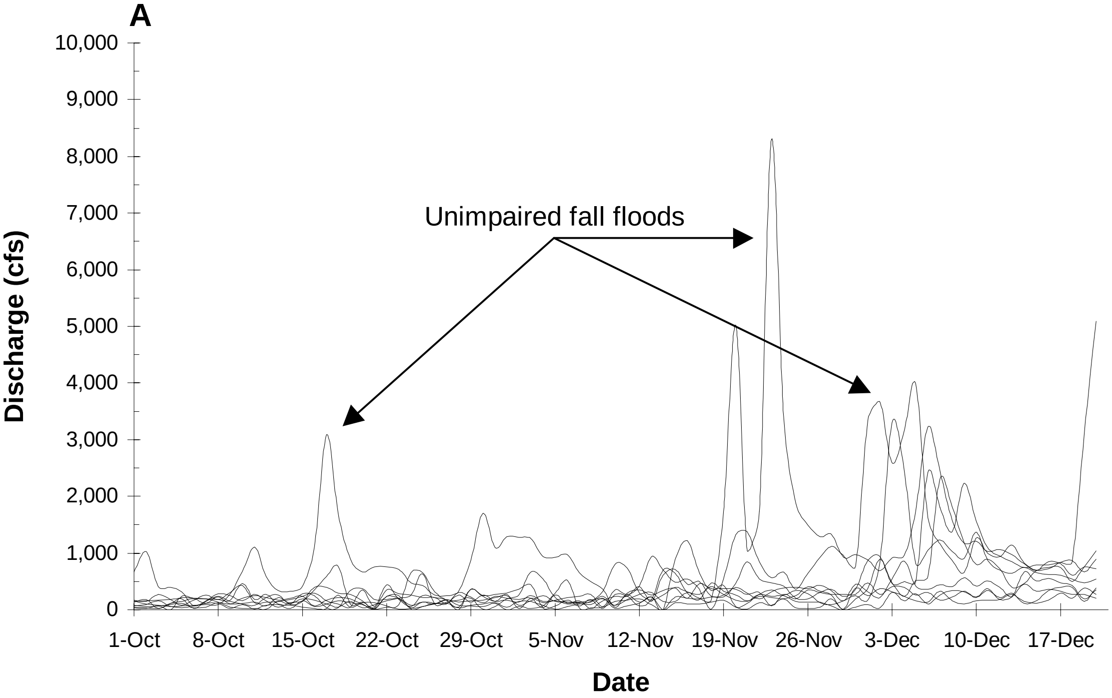
2.4.2.3. Hydrologic conditions and chinook life history

Adaptive responses to the hydrologic regime were critical elements molding chinook life history strategies. Not only did streamflow and floods form and maintain instream habitat, but chinook salmon also adapted to the natural variability in magnitude, timing, duration, and frequency of streamflow events. Although only relatively small portions of their lives are spent in the river environment, these life stages are critically important to the population.

We analyzed unregulated hydrograph components to examine historical flow patterns with significance to chinook salmon life history adaptations. These conditions were then compared to the current hydrologic conditions set by the FERC NDPP license amendment in the Settlement Agreement.

<u>Immigration and spawning</u>. Chinook salmon immigration and spawning occurred during fall baseflows and fall storms of low magnitude and short duration. Unimpaired average fall baseflows ranged from 332 cfs to 542 cfs during Critically Dry and Extremely Wet water years, respectively, and frequently exceeded 1,000 cfs during wetter water year types. Variability in streamflow during the spawning season, combined with diverse channel topography, provided variation in depth and velocity that was an important mechanism to distribute spawning within different channel locations. This mechanism maximized available spawning habitat (Figure 2-32), and probably reduced scour and superimposition mortality on incubating eggs.

Minimum streamflows during the spawning season are now determined by the FSA flow schedule (Table 2-5), which sets steady, non-fluctuating flow releases, and does not incorporate historical streamflow variability. The effects of flow regulation on the hydrograph during spawning can be seen by comparing representative unimpaired and regulated water years (Figure 2-33). Regulation of fall baseflows at unnaturally low streamflows may produce the undesirable consequence of limiting spawning to the center of the channel as opposed to margin habitat (Figure 2-32), encouraging salmon to construct their redds on top of pre-existing redds (redd superimposition), and increasing the vulnerability of egg pockets to scour during moderate or large floods.



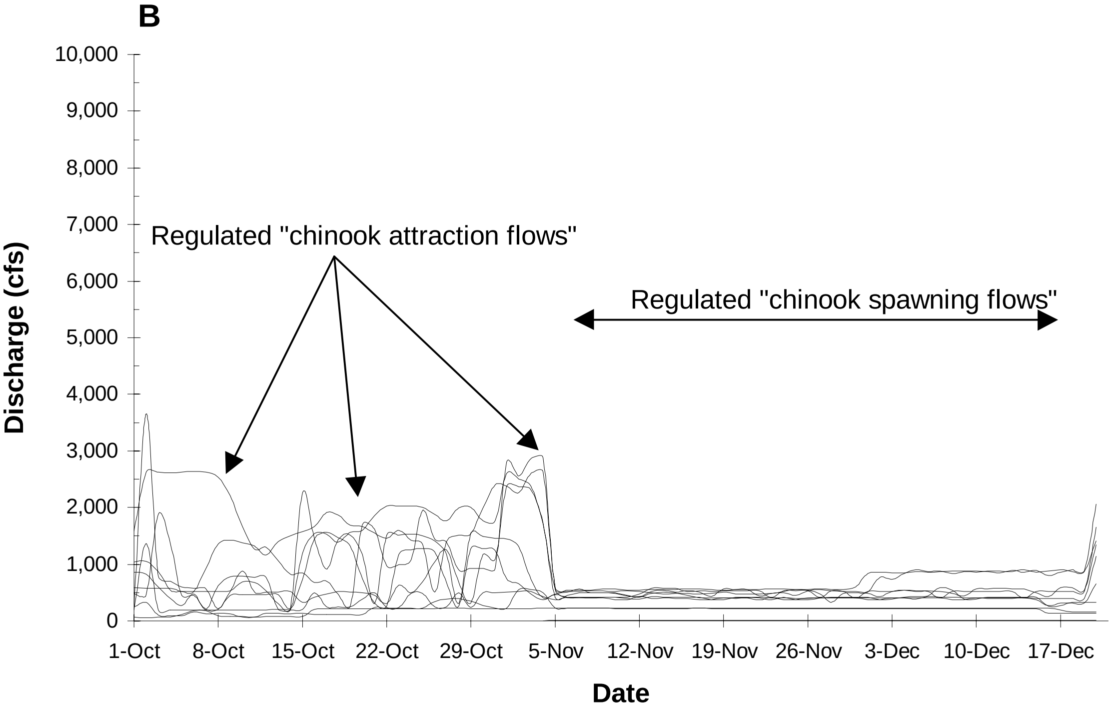


Figure 2-33. Daily average flows during chinook Salmon spawning (Oct. 1 to Dec. 20) for: A) typical unimpaired WY 1947-1956, and B) typical regulated WY 1973-1982. Variability in the unimpaired flow regime may have been an important mechanism for distributing spawning habitat to different locations within the active channel.

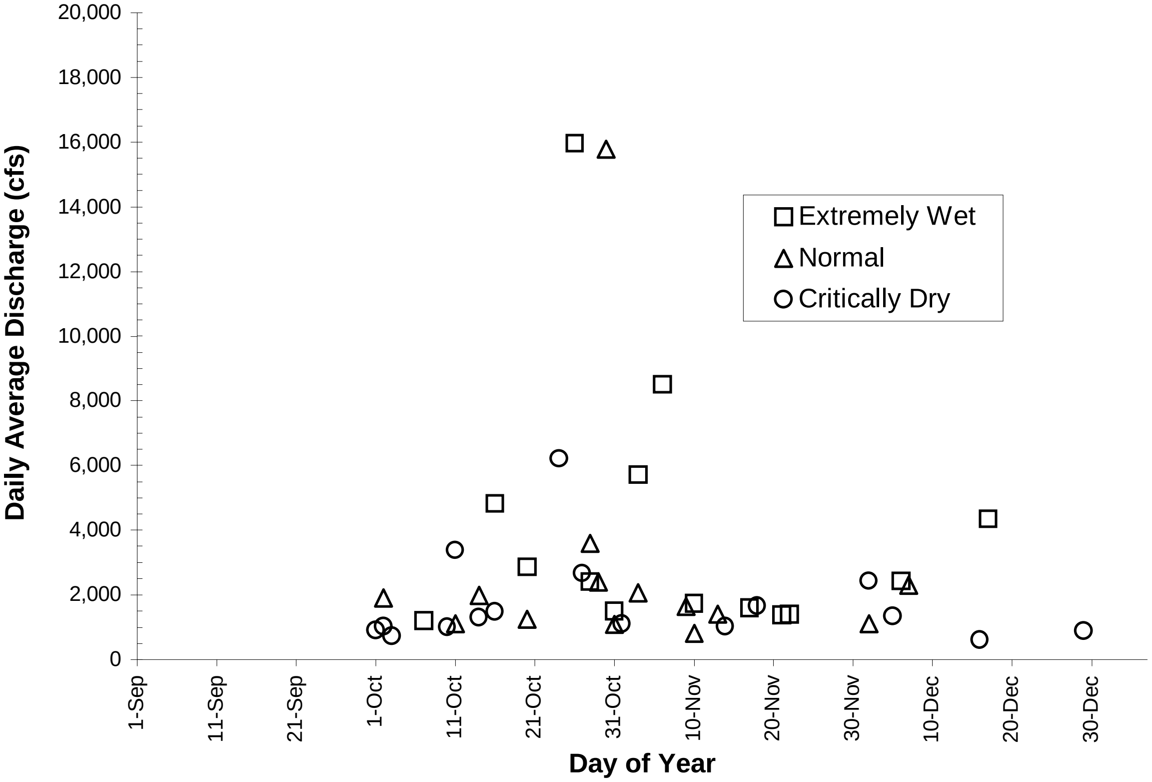


Figure 2-34. Magnitude and timing of the first fall storms of each water year of record, showing minimal differences between water year classes.

The magnitude and timing of fall storms were evaluated to determine the effects of these events in encouraging or disrupting chinook emigration and spawning patterns. Fall storms may be an important trigger for upstream migration. The first flood pulses after the summer low-flow months also may have been an important hydrograph component to remove fine sediments from spawning gravels (Lisle 1989). Unimpaired fall storm magnitudes ranged between 1,400 cfs and 16,000 cfs for Critically Dry and Extremely Wet years, respectively (Figure 2-34). The natural variability in fall hydrographs has been eliminated by the FSA flow schedule requirement of a 45-day steady spawning flow, and has been replaced by a single “fall attraction pulse flow” ranging up to 2,500 cfs and lasting only 2 or 3 days.

Egg incubation and development. Two hydrograph components, winter baseflows and winter floods, occur during egg incubation and development. Winter baseflows perform essential functions of oxygen delivery and waste removal. Winter storms represent a potentially significant mortality agent if the channelbed (and redds) scours to the depth of chinook egg pockets. Unimpaired baseflows during incubation (Oct-16 to Mar-31) ranged between 775 cfs and 2,800 cfs for Critically Dry and Extremely Wet water years, respectively. Flood magnitudes during incubation and emergence included the entire range of unimpaired winter floods determined by flood frequency analyses (Table 2-3), and ranged between 3,400 cfs and 23,000 cfs for daily average floods during Critically Dry and Extremely Wet water years, respectively. Unimpaired peak flows occasionally exceeded 100,000 cfs (1862, 1956, 1997). Winter flood magnitudes are presently regulated by NDPP operations with the Army Corps of Engineers (ACOE) allowing a maximum discharge of 9,000 cfs at Modesto below Dry Creek, although releases have been up to 10,400 cfs at La Grange and flows have reached 12,000 cfs at Modesto, excluding the 1997 flood. Flood releases in the upper gravel-bedded reaches can be substantially lower for short periods when unregulated streamflows from Dry Creek are high.

Juvenile rearing and emigration. Fry and juvenile rearing patterns were likely related to winter baseflow magnitudes and timing. Water years with consistent baseflows and lower magnitude flood peaks enabled more fish to rear in upstream reaches near the spawning grounds. Water years with more variable flows and larger magnitude winter and spring snowmelt flood peaks probably distributed fry and juveniles downstream to lower sand-bedded reaches of the Tuolumne River, the San Joaquin River, and Bay/Delta estuarine rearing habitats, where historically high quality rearing habitat existed.

Smolt emigration was directly tied to snowmelt runoff and instream temperature conditions beginning in late March and continuing through June. By this time most chinook had left the river system. Higher spring outflows during wetter years probably extended the in-river duration of rearing by providing cold water temperatures into later summer months: July, August and even September of some years. Downstream migration into the Bay/Delta and the ocean was a pivotal stage in the life history of chinook, as they were more vulnerable to high temperature and predation. High spring runoff reduced predation on emigrating juveniles by reducing downstream migration time and by lowering temperatures (discussed in greater detail in subsequent sections). High flows also increased turbidity, which reduced predation efficiency by sight feeders (e.g., black bass). The average peak discharge for snowmelt runoff ranged between 4,500 cfs and 13,000 cfs for Critically Dry and Extremely Wet water years, respectively, with median peak magnitudes in excess of 20,000 cfs. Additionally, the combination of Tuolumne, Merced, Stanislaus and San Joaquin River flows significantly increased the magnitude of streamflow through the Bay/Delta. The timing of the spring snowmelt flood peak was related to snowpack magnitude (the wetter the snowpack, the later the peak), and varied from early May in Critically Dry years to mid-June for Extremely Wet years (Figure 2-10).

The importance of high spring flows during outmigration on smolt survival has been shown for the Tuolumne River (USFWS 1987; Kope and Botsford 1990; USFWS 1992; EA Engineering 1997; CDFG 1998) and for other Central Valley rivers as well (SPCA 1997). Studies on the Tuolumne River under FERC-mandated 1971 and 1986 study plans determined which factors influenced the rate and magnitude of changes in population size of the San Joaquin system chinook salmon. The severity of mortality during smolt outmigration was inversely related to discharge. They hypothesized that high spring discharge reduced mortality by reducing water temperature, reducing predation by increasing turbidity and water velocity, diluting pollutants, and reducing the proportion of smolts entrained in delta water export facilities.

The link between streamflow volume during chinook smolt outmigration and survival to recruitment is a fundamental issue in Central Valley chinook salmon and water management. The relationship between spring flows, in-river rearing and outmigration conditions, and the rate and magnitude of changes in population size of San Joaquin River chinook salmon, was explored by use of a statistical model developed (EA 1992, 1996). The model incorporates both density-independent mortality influenced by spring flows, and density-dependent mortality represented by a Ricker-type spawner-recruit relationship. The model shows that spring flow correlates closely with escapement and is a key factor in the dramatic fluctuations in chinook salmon population levels. Mechanisms responsible for the Ricker spawner-recruit relationship, in which adult chinook escapements beyond a threshold progressively reduce recruitment of juveniles into the population, will be discussed in more detail below.

Additional evaluations relating spring streamflows to smolt survival are currently being conducted by CDFG and TRTAC. The CDFG study evaluates the entire Tuolumne River and San Joaquin River, and includes portions of the Bay/Delta extending to Chipps Island at the head of Suisun Bay (CDFG 1998). TRTAC studies are also evaluating the relationship between smolt survival and spring streamflow in discrete reaches of the Tuolumne River, and specific restoration project reaches. Preliminary results indicate juvenile and smolt survival are low during low spring runoff conditions, and survival is poor in the Mining Reaches.

2.4.2.4. *Habitat conditions and chinook life history*

Alluvial rivers are typically hot-spots of biodiversity (Tietje et al. 1991; Stanford et al. 1996) and may support core fish populations which serve as stable population sources for re-dispersal in response to local extinction (Lichatowich et al. 1995). Within alluvial reaches of the Tuolumne River, local habitat complexity was historically maintained by high rates of energy and material input, storage, and transport; increased corridor width as the river emerged from confined canyon reaches into the valley, and consequent increased nutrient inputs from adjacent riparian vegetation; higher seasonal variability in streamflow and temperature; and the presence of nutrient-rich floodplain soils (Stanford et al. 1996). Without pre-settlement descriptions of physical habitat, we analyzed channel and floodplain habitat structure on the spatial complexity provided by the alternate bar channel morphology. Alternate bars are the primary geomorphic units of alluvial rivers and represent the fundamental habitat template for all freshwater life stages of chinook salmon and for other species (Figure 2-36). The 1937 aerial photo series also proved useful. The topographic diversity of the channelbed and active bar surfaces provide a diversity of habitat for chinook salmon, including:

- adult holding in pools during immigration;
- preferred spawning substrate and physical micro-environment (depth and velocity);
- high quality egg incubation environment in spawning gravels;
- winter and spring rearing in slack water along bar surfaces, and in shallow backwater zones behind point bars;
- summer (yearling) rearing in pools, riffles and runs;
- fry and juvenile refugia during floods on inundated bar and floodplain surfaces;
- abundant food production areas;
- large organic debris load (large wood) that provided habitat structural diversity and habitat for fish and aquatic invertebrates.

Immigration and spawning. As discussed earlier, the alternate bar is composed of an aggradational lobe and a scour pool (Figure 2-16). The outside of the meander is the location of the pool or slow-moving run. A meandering channel erodes banks and undercuts trees (cottonwood, alder) providing tree and rootwad woody debris input into the river, which increases pool habitat complexity (Figure 2-26). Pools provide velocity shear zones, and cover from turbulence, undercut banks, depth, shade, large boulders, bubbles, and woody debris. Additionally, pools may provide temperature refugia when ambient temperatures are critically high.

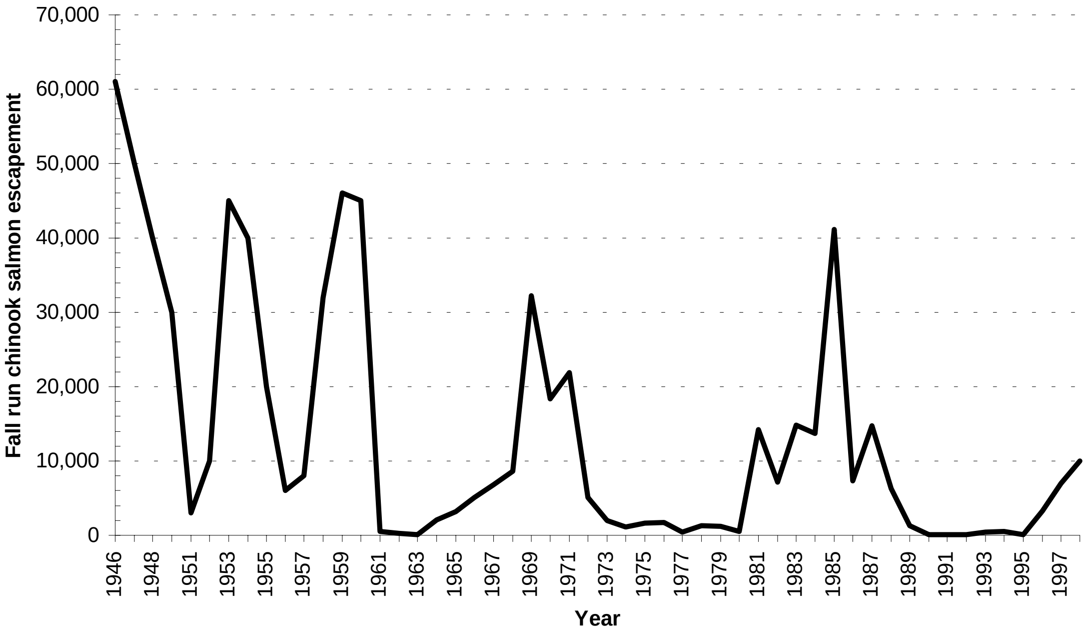


Figure 2-35. Historical chinook salmon escapement estimates, showing trends in population booms and crashes.

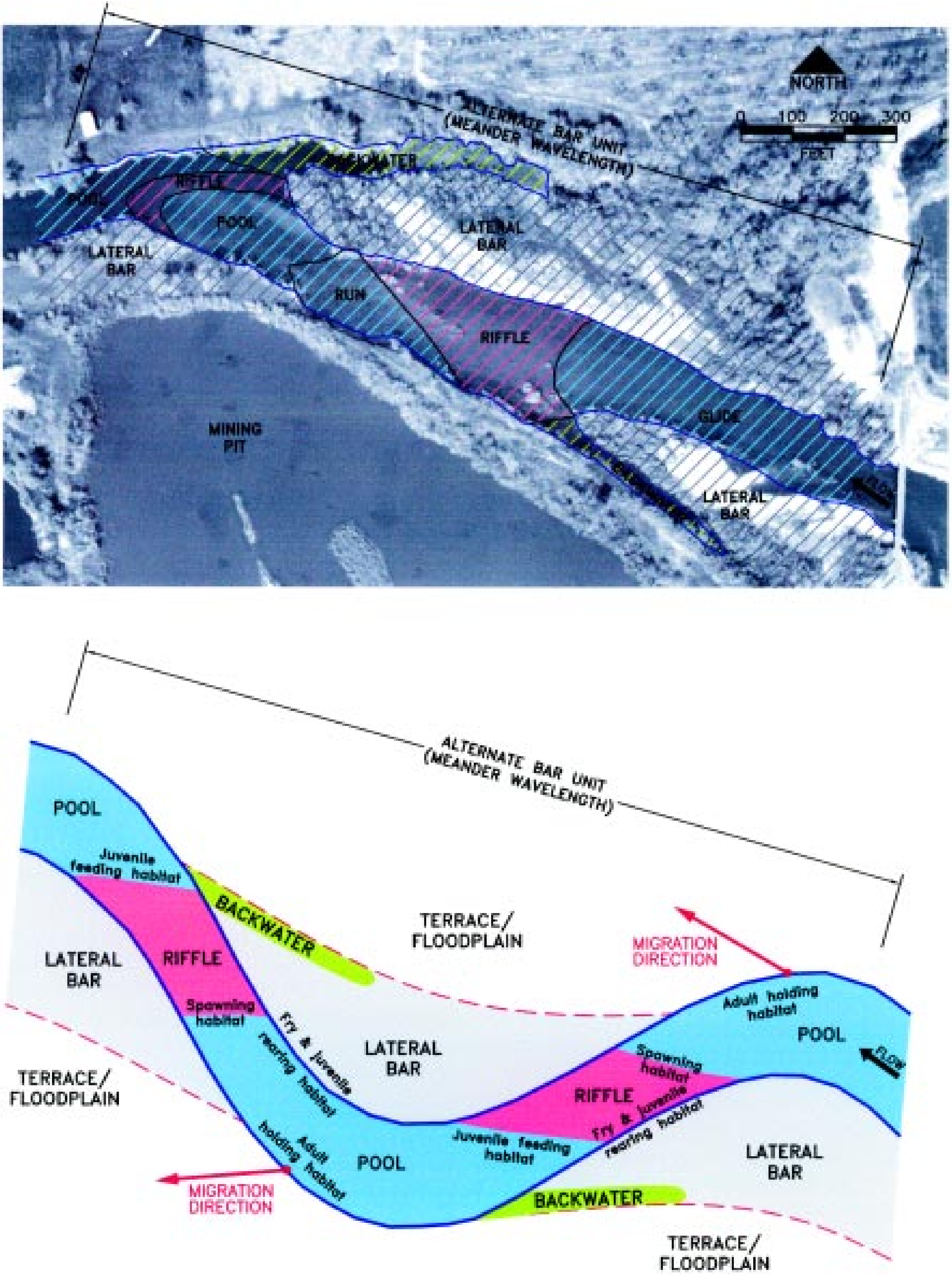


Figure 2-36. Idealized alternate bar sequence showing location of habitat features used by chinook salmon.

Suitable bed material and hydraulic conditions at the pool-riffle transition (pool-tail) provide ideal spawning conditions for salmon. Gravel stored in pool tails and riffles are subject to higher frequency of scour and redeposition, and these patches of gravel are consequently well-cleaned and sorted to a size class preferred by spawning salmon. Scour and fill processes can remove fine sediment and discourage embeddedness or armoring of the surface layer, facilitating redd excavation by the chinook salmon female. Additionally, water inflow associated with zones of accelerating water velocity (at pool-tails) creates higher intragravel flow, facilitating oxygen delivery and waste removal from salmonid egg pockets.

Spawning gravel availability. Habitat suitable for spawning on the Tuolumne River is finite, imposing an absolute limit on production at some level. A 1986 estimate of spawning habitat (EA 1992) enumerated 72 riffles and 2.9 million ft^2 of riffle area (at 230 cfs). By assuming all riffle area was spawnable (a generous assumption), and a spawning area requirement of 216 ft^2 for each spawning pair, the study concluded that the available spawning gravel in the Tuolumne River below La Grange dam would provide between 10,000 and 13,500 spawning sites, at 230 cfs. These studies concluded that spawning habitat was a significant factor limiting salmon production. Redd mapping at riffle 3A (Figure 2-37) shows the clumped distribution and superimposition of redds in the riffle and pool tail, with spawning concentrated near the stream margins. Increased flows would inundate progressively more spawning area along the point bar adjacent to the riffle, potentially reducing superimposition. CDFG has recommended experimenting with flow variability as a way to distribute spawners and help reduce redd superimposition. District studies (EA 1992) also recommended implementing management activities to distribute spawners more evenly throughout the spawning reaches and reduce superimposition.

Comparisons to historical conditions are impossible because historical data estimating spawning areas and spawning riffle conditions are unavailable. In addition, reaches that were relatively undisturbed in the 1937 aerial photo sequences (RM 25-40) have since been dramatically altered by aggregate extraction. In contrast, upstream reaches affected by gold dredger mining in the early part of the century (RM 47-50), were subsequently "reconfigured" following removal of dredger tailings for NDPP construction. These reaches are now more productive spawning reaches than under degraded channel conditions caused by dredge mining.

The alternate bar morphology at RM 38 is one of the best examples available showing an historically dynamic channel morphology (Figures 2-19 and 2-38), to which contemporary conditions can be compared. These alternate bars provided a variety of habitat for chinook: fry rearing habitat along channel margins; fry and juvenile refugia in backwaters, lateral scour channels, and on inundated bars during floods; spawning habitat at pool-tails and riffles; and adult holding habitat in deep pools and in turbulent areas. The river thalweg crossed the aggradational lobes between the two upstream point bars, creating riffle 31, and then again forming riffle 32. At the downstream edges of point bars, backwater zones provided rearing and refugia for chinook, as well as habitat for riparian and wildlife species.

We used the 1950 aerial photo sequence to compare past spawning habitat use with contemporary habitat use. Escapement during the 1950 spawning season was an estimated 30,000 adult chinook, a relatively high escapement year. In the 1950 photos, riffle 31 is a distinct, heavily spawned area, conservatively estimated to be 50,000 ft^2. Based on a conservative estimate of the area of spawning habitat required, 216 ft^2[3] per spawning pair (Burner 1951; EA 1992), riffle 31 in 1950 could have accommodated at least 231 redds. Visual count of redds at riffle 31 directly from the aerial photos ranged from 42-140 redds.

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[3] *Burner (1951) provided an "average area of fall-run chinook redds" (54 sq ft) and an "area recommended for each spawning pair" (216 sq ft), noting that the spatial requirements for each spawning pair may exceed the area of the completed redd. Burner noted that wherever sufficient spawners were present to utilize virtually all available spawning habitat, area surrounding the redd amounted to three times the aarea occupied by the redd. Burner thus suggested that a conservative estimate of the number of salmon a stream could accommodate could be obtained by dividing the area suitable for spawning by four times the average area of a redd. The CDFG (1990) Central Valley Salmon and Steelhead Restoration and Enhancement Plan suggests the average size of chinook salmon redds is approximately 165 sq ft, and the territory required for a spawning pair to range between 200 and 650 sq ft, but suggest the seasonal requirements for minimum spawning area per female is 75-100 sq ft.*

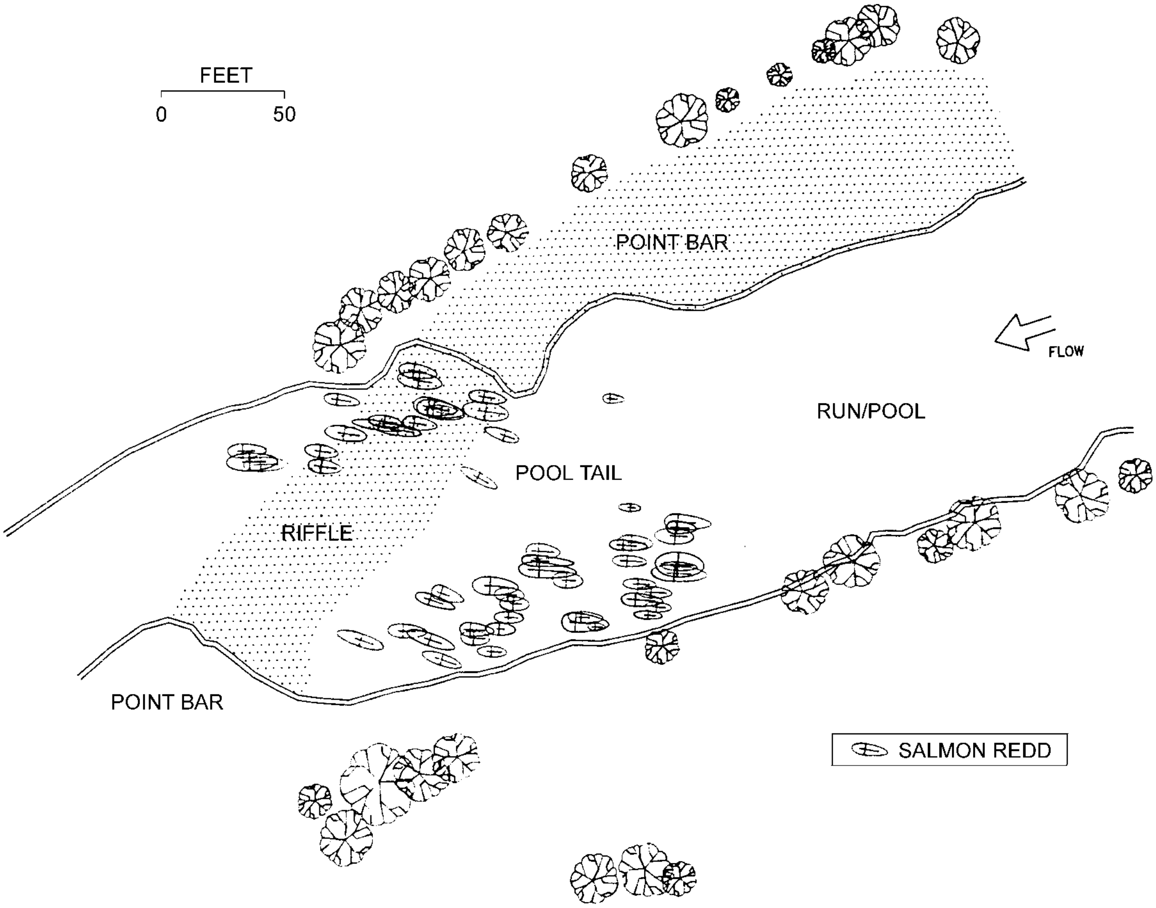


Figure 2-37. Location of salmon redds in riffle 3A (RM 49.4), showing use of riffle and pool tail habitat for spawning, and a preference for lateral (margin) zones. Redd superimposition is indicated where redd boundaries overlap. (from EA 1992)

Figure 2-21 shows the planform morphology of riffle 31 in 1993. The previously dynamic point bar has become fossilized by riparian vegetation encroachment. Rearing habitat along the shallow margins of the bars is reduced to narrow strips between the wetted channel edge and the encroached vegetation. Many of the backwater habitats present in Figure 2-38 are either severely degraded by warm water temperatures and water hyacinth, or are gone. Along the south bank, entire floodplains and terraces were eliminated by aggregate extraction. These surfaces were replaced with pond habitat, separated from the channel by steep-banked dikes protected from erosion with rip-rap.

Previously high quality and heavily used spawning gravels in riffle-31 have been reduced in overall quantity and quality:

- Estimates of spawning habitat availability for R31 from 1986 aerial photos (EA 1992) quantified only 25,000 ft^2 of available spawning habitat. Field measurements conducted in 1999 estimated only 4,500 ft^2 of suitable spawning habitat at 277 cfs. (McBain and Trush and Stillwater Sciences 2000) indicate a loss of more than half the spawning area, from 50,000 ft^2 to 25,000 ft^2 of available spawning habitat.
- The average “high” redd count from redd surveys conducted from 1981 to 1995 for R31 (CDFG) was 6.8 redds per year.

A similar analysis of available spawning habitat was extended to 11 riffles in the reach between RM 35.5 and 40.2 (Table 2-9). Spawning gravel utilization was estimated from 1950 photos for those 11 riffles with visible spawning activity, and then compared to spawning gravel estimates from

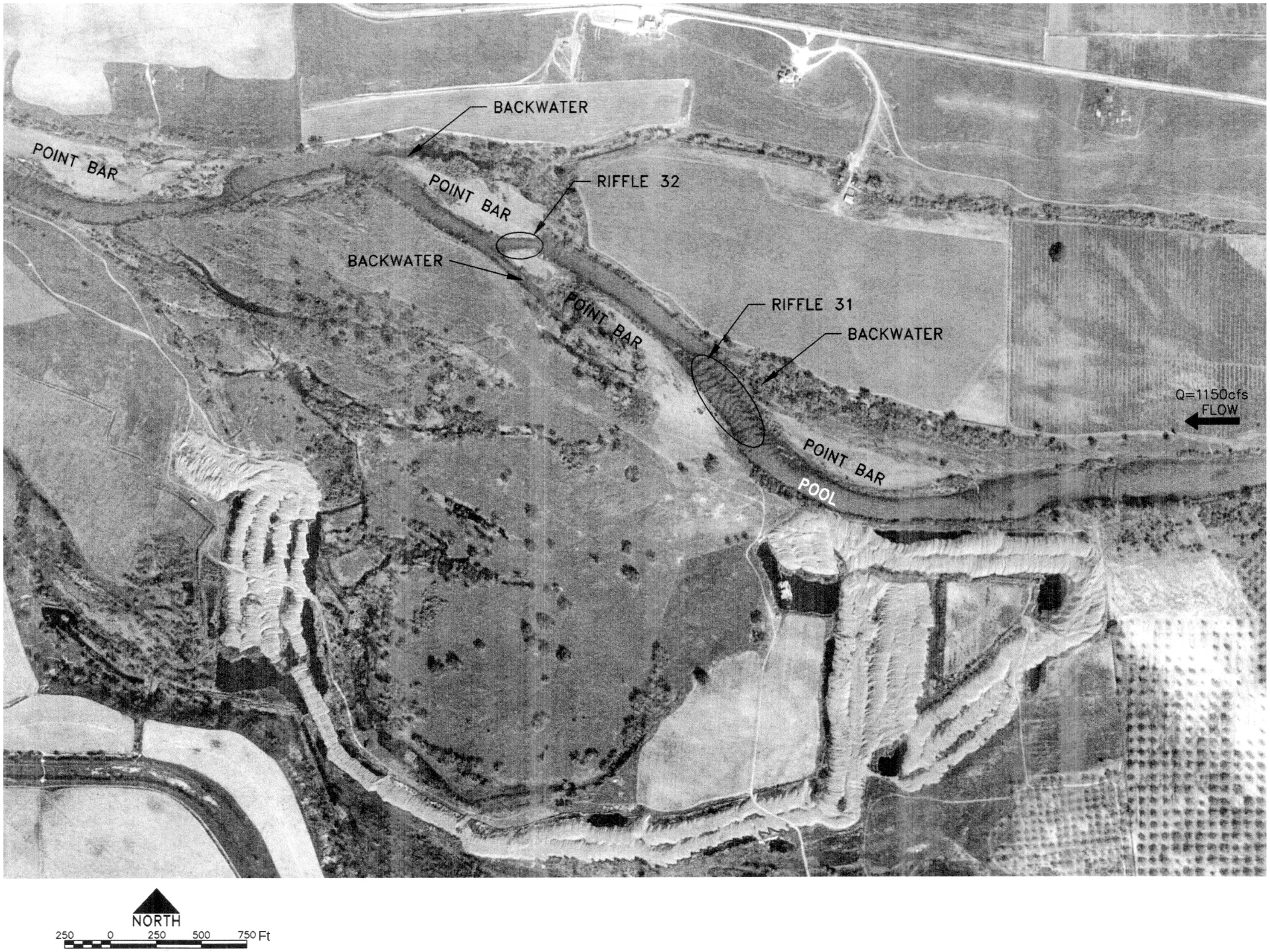


Figure 2-38. Aerial photograph from March 1950, showing the alternate bar sequence at RM 38.0, including point bars, scour pools, backwater areas and spawning riffles R31 and R32.

1986 aerial photos (EA 1992). Most riffles showed trends similar to riffle 31: an average 43% reduction of available spawning habitat in response to impeded bedload supply, confinement of the channel by aggregate mining and dikes, scour and loss of existing gravels, agricultural encroachment, and riparian encroachment. Bed coarsening from the lack of gravel particles has also reduced the overall quality of the remaining available habitat. Additionally, quantifying spawning habitat from aerial estimates of spawning gravel or riffle area has considerable limitations, because it assumes that all available gravel within a riffle is suitable for spawning.

Because no information is available to document the spawning habitat conditions in the rest of the Tuolumne River prior to major channel alteration (1850), we can only speculate that changes to spawning gravel quantity and quality are likely comparable along the entire river corridor: slow attrition of riffle area by fossilization of alluvial features, degradation by fine sediment infiltration, loss of usable spawning habitat by coarse sediment supply deficit and consequent coarsening of the channelbed particles.

The January 1997 flood had additional impacts on spawning gravels, particularly in the reaches where dikes, bridges, and agricultural encroachment have narrowed the floodway. Entire riffles (e.g., 1A, 1C, 6, 9B, 11, and others) were scoured and redeposited downstream, creating long, deep runs followed by steep riffles unsuitable for chinook spawning. Scour and mobilization of the channelbed is beneficial to spawning gravel substrates, but only if sediment is available from upstream sources to redeposit, maintaining the dynamic quasi-equilibrium in scour and deposition volumes discussed earlier. Lack of in-channel gravel storage and supply resulting from dams and bedload impedance reaches has slowly depleted available spawning habitat. In the absence of gravel introduction and channel rehabilitation, this process will continue to further degrade spawning habitat.

Redd superimposition. The effects of reducing the available spawning gravel quantity and quality were documented by the Districts (EA 1992, Appendices 6, 7, 8) by assessing the distribution of spawners in the lower Tuolumne River, the degree and effects of superimposition within five intensively studied riffles in the upper river, and egg and alevin survival. Their conclusion was that lack of gravel supply, combined with chinook behavioral preferences for spawning in the uppermost reaches of the Tuolumne River, caused substantial superimposition of redds, even in low escapement years. Superimposition was identified as the primary mechanism of density-dependent mortality, and resulted in the Ricker spawner-recruit relationship. These studies concluded that superimposition is a significant source of mortality based on the following information:

- The 2.9 mile-long section 1A (between Old La Grange Bridge, RM 50.5, and Old Basso Bridge, RM 47.6) was the most heavily used spawning section, receiving an average of 53% of the spawners in surveyed sections. Yet this section contained only about one-fifth the total spawning gravels (673,600 ft^2). In 1985 at an escapement of 40,000 (the largest spawning run since NDPP), an estimated 11,476 female spawners used Section 1A, whereas Section 3 (RM 25 to 34) contained 821,000 ft^2 of spawning gravel, but was relatively little used.
- In 1988, at a relatively low escapement of 6,300 adults, an estimated 1,457 females spawned in section 1A, and superimposition resulted in an estimated 20% destruction of eggs. Of the 384 redds identified in the 5 study riffles during the 1988 spawning season, 169 redds (44%) were built on top of pre-existing redds (Figure 2-37).
- Maximum production for the Tuolumne River was estimated to occur at an escapement of 15,000 adults. Beyond this escapement, additional spawners actually decreased production because of superimposition-induced mortality. This resulted in a Ricker-type spawner-recruit relationship. This estimate may in fact be too high, considering the spawning habitat attrition that has occurred since 1988, and the questionable assumption that the entire riffle area is suitable for spawning.

Egg incubation and development. Gravel quality is a key determinant in successful salmonid embryo incubation and emergence (Harrison 1923; Hobbs 1937). Historically, good quality spawning gravels were maintained in the Tuolumne River by a dynamic equilibrium in fine and coarse sediment supply and routing. Frequent scour and redeposition of bed sediments periodically removed fine sediments from spawning gravels and deposited them on floodplain surfaces. Gravel quality is now severely degraded in the Tuolumne

Table 2-9. Comparison of estimated riffle and spawning areas from 1950 photos with contemporary (1986) conditions in the Tuolumne River Corridor.

RIFFLE	LOCATION (RM)	ESTIMATED RIFFLE AREA (FT^2)		PERCENT REDUCTION	1950 ESTIMATED REDD CAPACITY**	AVERAGE "HIGH" F COUNT 1981-19
		1950	1986			
28A	40.2	24,696	29,887	0%	114	8.4
28B	39.5	26,460	10,381	61%	123	8.4
29	39.1	56,448	43,994	22%	261	13
30B	38.5	35,280	13,496	62%	163	8
30C	38.4	35,280	21,326	40%	163	0
31	38.0	86,436	25,033	71%	400	6.4
33	37.7	56,448	29,472	48%	261	6.7
34B	37.5	42,336	8,005	81%	196	6.1
36B	36.5	63,504	53,974	15%	294	4.1
37	36.2	28,224	25,207	11%	131	3.3
38	35.5	76,356	26,316	66%	354	5.9
AVERAGE		48,315	26,099	43%	224	6

** Based on area recommended for each spawning pair of 216 sq ft from Burner (1950).

River, because fine sediments have accumulated in the low flow channel. Elimination of coarse bedload supply from upstream reaches by La Grange Dam, reduction of scouring and channel-forming flows, increased inputs of fine sediments (particularly from Gasburg Creek), and reduced frequency of flows that deposit fine sediments on the floodplain, have all contributed to the poor quality of spawning gravels.

The Districts assessed gravel quality of eight riffles in 1987 and 1988 (EA 1992), by analyzing the particle size distribution of 72 McNeil gravel samples in riffles prior to spawning and in redds after the fry had emerged. The particle size distribution was then used to predict egg survival-to-emergence using the methods of Tappel and Bjornn (1983). The results poor spawning gravel quality and survival to emergence in the Tuolumne River. The average predicted survival for baseline spawning gravels (prior to spawning) was 16 percent. The average predicted survival in redds increased to 34 percent. The increase was due to the effects of spawning fish cleaning fine sediment from the gravel during redd construction. These estimates were then corroborated by survival estimates determined by emergence trapping of chinook salmon redds in 3 riffles in 1989, which, in conjunction with length-fecundity data provided by CDFG (Loudermilk et al. 1990), showed average survival of 32 percent, and ranged from 0 to 66 percent.

Gravel quality analysis was also performed at 20 riffle sites in the upper 15 mile spawning reach by the Department of Water Resources (DWR 1994). The study employed non-standardized bulk sampling methods for sediment removal by excavating underwater samples with a shovel, a method that may underpredict fine sediment fraction because an unquantifiable portion of the fine sediment fraction may be lost during excavation. They concluded that existing gravel in the assessed reaches is “generally adequate to support chinook salmon spawning”. For the 20 combined samples analyzed (surface and subsurface particles), the percentage of fine sediment finer than 1.2 mm averaged 5.8%.

Rearing and emigration. Chinook salmon fry emerge from the gravels during winter months when high magnitude floods historically occurred. Evidence suggests that some chinook fry emigrated to the San Joaquin River and Delta shortly after emergence, or were displaced there by high flows or unfavorable temperature conditions. Rearing also occurred in the lower sand-bedded reaches and on the spawning grounds (gravel-bedded reaches) (EA 1997).

The margins of point bars and backwater zones downstream of point bars generally provide suitable depth and velocity conditions, substrate composition and cover, and an abundance of benthic and terrestrial invertebrate food resources. Figures 2-17, 2-18, and 2-27 show historical alternate bar sequences in the sand-bedded zone. The key feature of the alternate bar morphology is that as river stage increases, the water’s edge progressively migrates up the point bar, leaving a band of suitable habitat along the stream margin at any stage, until the water surface elevation exceeds the point bar elevation and the entire bar inundates. The point bar and floodplain are thus important habitat refugia for rearing juveniles during higher flood stages.

Contemporary conditions have changed river channel morphology considerably, particularly due to the effects of agricultural and urban encroachment onto floodplains and lower bar surfaces (Figures 2-21, 2-23, and 2-24). Shallow rearing habitats along stream margins have been reduced or replaced with lower quality, deeper margin areas with poorer depth/velocity profiles. Additionally, vegetative encroachment and riparian berm formation along river banks prevent the river from progressively expanding onto lateral bars and wide, flat floodplains as river stage increases, and fry and juveniles may be less able to access high flow refugia. This may in turn decrease survival by forcing juveniles and smolts to rear in the lower sand-bedded reaches, the San Joaquin River, and in the Bay/Delta.

2.4.2.5. *Biological interactions and chinook life history*

Predation by introduced species of bass may be a dominant source of mortality under low flow conditions for juvenile chinook in the Tuolumne River (EA 1992). Smolt survival studies conducted by CDFG in 1987 at 600 cfs estimated that 69% of 90,000 smolts released in the upper Tuolumne did not survive the 3-day migration to the San Joaquin river confluence. One hypothesized mechanism for this mortality was predation. The Districts conducted a pilot study in 1989 and a full study in 1990 to determine (1) predator densities (largemouth and smallmouth bass) in the lower Tuolumne River and (2) rates of predation on juvenile chinook salmon by largemouth and smallmouth bass, the primary predator species.

The highest concentrations of largemouth bass were found in the special-run-pools (SRPs) which are former in-channel aggregate extraction pits. Abundance estimates ranged as high as 181 bass in SRP 2, located immediately below the primary spawning reaches. Predator abundance in Section 1 (RM 25-52) was higher than in Section 2 (RM 0-25), and densities (abundance per acre or bank mile) were considerably higher in run-pool units than in special-run-pool units, although confidence intervals were also much broader. Based on estimates for each of these habitat types, the largemouth bass population extrapolated for the entire 52 mile river was estimated to be 10,130 ± 5,164 (95% confidence interval) (EA 1992).

Predation rates for largemouth and smallmouth bass were low or undetected during March/April sampling, but increased dramatically for both species in Section-1 SRPs during a May pulse flow release. The mechanisms for this increase are unknown. Conservative predation rate estimates were 1.0 and 3.6 salmon per day for largemouth and smallmouth bass, respectively. Based on 1990 population estimates, largemouth and smallmouth bass could have consumed more than 17,000 smolts per day during emigration, enough to explain the disappearance of an estimated 60,000 CWT smolts lost in the 1987 study.

The studies concluded that reduced predation may be the mechanism by which high spring flows increased smolt survival and increased recruitment. Increased flow reduces the time smolts are exposed to predators, increases turbidity which inhibits the predator feeding efficiency, reduces the concentration of predators in main channel areas by forcing them into warm-water refugia, and reduced the chronic thermal stress to which smolts are subject at higher temperatures (discussed in greater detail below). Recent CDFG and TRTAC research also indicates that spring flows are related to smolt survival (CDFG 1997; CDFG 1998).

The smallmouth bass population could not be reliably estimated due to low capture rates, but smallmouth bass are known to begin feeding at lower water temperatures than are largemouth bass, and therefore may have an equally significant (or greater) impact on juvenile salmon as largemouth bass. In addition to largemouth and smallmouth bass populations, several other predator species are known to occur in the lower Tuolumne River, with (presumed) smaller populations that collectively could also impact juvenile salmon cohorts; striped bass (*Morone saxatilis*), Sacramento pikeminnow (*Ptychocheilus grandis*) and potentially catfish species.

2.4.2.6. *Other limiting factors*

Bay/Delta and ocean factors. Two additional factors, high juvenile mortality in the Bay/Delta and at Delta pumping plants, and sport/commercial ocean harvests that deplete adult stocks, have significant detrimental effects on adult escapements. Modeling studies for the Districts, based on experimental data collected by CDFG, indicate that up to 44% of chinook salmon juveniles emigrating down the San Joaquin river between 1973 and 1988 died because of entrainment in CVP and SWP facilities (EA 1992). USFWS studies support these conclusions (USFWS 1987). Mitigation measures currently proposed or already implemented, such as installing the Old River barrier, and reduced pumping during emigration, should significantly reduce Bay/Delta mortality.

Ocean harvest directly reduces chinook escapements. Harvest management thus represents a powerful tool for increasing the population of returning spawners. This aspect of salmon population management is especially crucial during low escapement years when small increases in the escapement size are magnified due to the lower adult/fry/juvenile densities and consequent higher survival levels.

Temperature. The effects of high water temperatures on chinook spawning, rearing, and emigration remain less well known than other limiting factors, yet high temperature at times may be a significant factor limiting the chinook population in the Tuolumne River and in the time spent in the San Joaquin River and Bay/Delta. The SNTEMP temperature model, developed for the 52-mile lower Tuolumne River, is capable of predicting 5-day average instream temperatures throughout the year (EA Engineering 1992, Appendices 17-19).

High water temperatures during rearing and smolt emigration are perhaps the most significant dam-related habitat alteration (apart from flow reduction and sediment blockage) in the Tuolumne River. For the period 1966 to 1984 (CDFG 1987), flows in May during smolt emigration were less than 5,000 cfs at La Grange in 13 of 19 years, and 8 of these 13 years had median water temperatures at Vernalis (on the San Joaquin River) exceeding 67.6 ºF (19.7 ºC). These temperatures were characterized by Rich (1987) as resulting in high chronic thermal stress. A study by Brett (1952) used chinook salmon from the Dungeness hatchery in Washington, and determined a range of upper incipient lethal temperatures of 73 ºF (22.8 ºC) to 77 ºF(25.0 ºC) , and 12-hour median lethal temperatures ranging from 71.2 ºF (21.8 ºC) to 80.6 ºF (27 ºC), depending on the acclimation temperatures. Water temperatures as high as 86 ºF (30 ºC) have been recorded near La Grange Dam in summer months. These high water temperatures on the Tuolumne River correspond to periods when there are few salmon in the river, but likely was the cause for the decline in “yearling” or over-summering salmon. Comparable temperature studies using San Joaquin River basin chinook have not been conducted, but results could differ from those obtained using northern races.

Not only are the effects of high water temperature direct (e.g., thermal stress, mortality), but high temperatures may also contribute indirectly to other limiting factors such as bass predation, smolt survival during emigration, spawning distribution, and incubation success. The first year of the fry emergence study (EA 1992) showed much lower egg survival (1-2%) than predicted based on gravel quality, and was attributed to mortality caused by high incubation temperatures. High ocean and Bay/Delta water temperatures have also been shown to cause egg mortality prior to the salmon entering their natal streams. In addition, beyond the seasonal affects of high temperatures on specific life history phases, high daily fluctuations in water temperature (ranging from 12 to 14 ºF daily) are known to occur at low flows.

High water temperatures are also most likely responsible for limiting habitat of yearling chinook salmon. Low summer flows and resultant high water temperatures can be lethal to summer rearing. The revised FERC flow schedules provide better conditions for summer rearing during wet years, particularly in the upper reaches near La Grange Dam. According to the SNTEMP model, 300 cfs in the summertime would provide 15 miles of habitat with suitable summer water temperatures for summer rearing.

2.4.2.7. Current status of chinook population

The San Joaquin River basin and Tuolumne River fall-run chinook salmon populations have fluctuated widely during the period in which run estimates are available (1940 to present), and are generally characterized by a series of years with high escapements alternating with years of extremely low escapements (Figure 2-35). The recent drought (1987-1992) resulted in population levels as low as 100 returning adults for three consecutive years. More recently, a succession of wet years has improved flow conditions. Changes have also been implemented in Delta export operations and ocean harvest that have probably benefited the salmon runs. Adult escapements have rebounded to 3,300, 7,200, and 8,800 adult spawners in 1996, 1997, and 1998, respectively. Preliminary estimates indicate that the 1999 escapement will approximate 1998.

While population levels appear strongly related to streamflows, improved hydrologic conditions alone may not restore populations to levels targeted by AFRP and CALFED. Recent improvements in escapement levels may suggest that wetter years alone have the potential to restore and maintain a viable salmon population at low escapement levels between 1,000 and 10,000. But to sustain escapements of 30,000 or more salmon will probably require a combination of improved streamflows and physical habitat. The AFRP has set preliminary production targets for the Tuolumne River fall-run chinook salmon population at 38,000 adults (harvest and escapement). These target production levels are based on twice the average escapement levels attained during the period 1967-1991 and a reduced harvest rate. The CALFED program has not set specific production targets, but their explicit goal of restoring sustainable populations of species by improving ecological conditions, and their collaboration with the AFRP program, suggests similar objectives.

2.4.3. Fish and wildlife resources

Restoring fundamental fluvial processes that characterized the historical Tuolumne River may not only aid in recovery and maintenance of a chinook salmon population, but will also improve conditions for a wide range of native fish and wildlife species. Similar to our description of the chinook salmon's adaptations to historical ecological conditions, other native inhabitants of the aquatic and riparian habitats provided by the Tuolumne River are also adapted to the historically "pristine" conditions that existed prior to extensive degradation of the landscape. In California, the amphibian, bird, and mammalian species diversity in Central Valley riparian zones represents the highest biodiversity found anywhere in the state (Tietje et al. 1991). Riparian and floodplain habitats support at least 50 amphibian and reptile species, 147 bird species, and 55 mammal species (Mayer and Laudenslayer 1988).

From their review of records dating from 1970, Brown and Ford (1992) identified 37 fish species occurring in the lower Tuolumne River (Table 2-10). Of these 37 species, 14 species are native and 23 species are introduced. The majority of the non-native species are members of the sunfish (Centrarchidae, 8 species), minnow (Cyprinidae, 4 species), and catfish (Ictaluridae, 4 species) families. Several of the sunfish species (primarily largemouth and smallmouth bass) support recreational fisheries, while at the same time pose a management concern as predators on juvenile chinook salmon.

Appendix B provides a comprehensive description (with tables) listing the riparian vegetation series and species found within the Tuolumne River corridor, including both native and exotic species. A complete list of all wildlife species present within the Tuolumne River corridor is beyond the scope of this report, but can be found within other sources. Important sources of information include Mayer and Laudenslayer (1988), Tietje et al. (1991), California Wildlife Habitat Relationships, CDFG (1997), Verner and Boss (1980), Storer and Usinger (1963), and see the Biological Resources Technical Background Report, Appendix D of TID EA/IS (1998). Examples of wildlife species that may be found in valley foothill riparian vegetation include ensatina (*Ensatina eschscholtzii*), common garter snake (*Thamnophis sirtalis*), warbling vireo (*Vireo gilvus*), ringtail (*Bassariscus astutus*) (CDFG 1997), mule deer (*Odocoileus hemionus*), coyote (*Canis latrans*), raccoon (*Procyon lotor*), opossum (*Didelphis virginiana*), river otter (*Lutra canadensis*), muskrat (*Ondatra zibethicus*), California ground squirrel (*Spermophilus beecheyi*), and striped skunk (*Mephitis mephitis*). Raptors, resident and migratory birds, California quail (*Callipepla californica*), great blue herons (*Ardea herodias*), snowy egrets (*Egretta thula*), great egrets (*Casmerodius albus*), and black-crowned night herons (*Nycticorax nycticorax*) also may be found within riparian zones (TID EA/IS 1998).

Numerous threatened, endangered or special status (TES) plant, bird, fish and wildlife species are also present within the Tuolumne River corridor, and additional information is available from the sources mentioned above for these TES species.

Restoring a more natural riverine ecosystem will promote conditions which favor native vs. non-native species, improving stability in socially and economically valued species such as chinook salmon, and in general promote a healthier environment.

2.5. SUMMARY

While advocating an ecosystem restoration strategy, we must acknowledge that our actions will never return the Tuolumne River to the historical conditions that existed prior to modern settlement and intensified land development of the Central Valley. Instead, restoring physical processes, such as channel-forming flows and coarse sediment introduction and transport, are intended to be used as *tools* for restoring and managing the resources of the Tuolumne River in accordance with other management strategies. Ecosystem restoration is by necessity experimentally-based, driven by hypotheses generated from our understanding of the physical processes and the adaptive responses of the biological community. Success of this approach is fundamentally dependent on adaptive management techniques to regularly evaluate successes and failures, and then refocus objectives.

Based on our historical evaluation of hydrologic records, aerial photographs, cross sections, and extensive literature review, we developed the Attributes of Alluvial River Ecosystem Integrity,

Table 2-10. Fishes of the lower Tuolumne River observed since 1981 in TID/MID fishery studies. N=Native.

Petromyzontidae - lampreys	
Pacific lamprey, *Lampetra tridentata* (Gairdner, 1836)	N
river lamprey, *Lampetra ayresi* (Gunther, 1870)	N
Acipenseridae - sturgeons	
white sturgeon, *Acipenser transmontanus* (Richardson, 1836)	N
Clupeidae - herrings	
American shad, *Alosa sapidissima* (Wilson, 1811)	
threadfin shad, *Dorosoma petenense* (Ghnther, 1867)	
Cyprinidae - carps and minnows	
common carp, *Cyprinus carpio* (Linnaeus, 1758)	
goldfish, *Carassius auratus* (Linnaeus, 1758)	
golden shiner, *Notemigonus crysoleucas* (Mitchell, 1814)	
hitch, *Lavinia exilicauda* (Baird & Girard, 1854)	N
Sacramento blackfish, *Orthodon microlepidotus* (Ayres, 1854)	N
Sacramento splittail, *Pogonichthys macrolepidotus* (Ayres, 1854)	N
hardhead, *Mylopharodon conocephalus* (Baird & Girard, 1854)	N
Sacramento pikeminnow, *Ptychocheilus grandis* (Ayres, 1854)	N
red shiner, *Cyprinella lutrensis* (Baird & Girard, 1853)	
fathead minnow, *Pimephales promelas* (Rafinesque, 1820)	
Catostomidae - suckers	
Sacramento sucker, *Catostomus occidentalis* (Ayres, 1854)	N
Ictaluridae - bullhead catfishes	
white catfish, *Ameiurus catus* (Linnaeus, 1758)	
brown bullhead, *Ameiurus nebulosus* (Lesueur, 1819)	
black bullhead, *Ameiurus melas* (Lesueur, 1819)	
channel catfish, *Ictalurus punctatus* (Rafinesque, 1918)	
Salmonidae - trouts	
chinook salmon, *Oncorhynchus tshawytscha* (Walbaum, 1792)	N
rainbow trout, *Oncorhynchus mykiss* (Walbaum, 1792)	N
Poeciliidae - livebearers	
western mosquitofish, *Gambusia affinis* (Baird & Girard, 1853)	
Atherinidae - silversides	
inland silverside, *Menidia beryllina* (Cope, 1866)	
Cottidae - sculpins	
prickly sculpin, *Cottus asper* (Richardson, 1836)	N
riffle sculpin, *Cottus gulosus* (Girard, 1854)	N
Percichthyidae - temperate basses	
striped bass, *Morone saxatilis* (Walbaum, 1792)	
Centrarchidae - sunfishes	
black crappie, *Pomoxis nigromaculatus* (Lesueur, 1829)	
white crappie, *Pomoxis annularis* (Rafinesque, 1818)	
warmouth, *Lepomis gulosus* (Cuvier, 1829)	
green sunfish, *Lepomis cyanellus* (Rafinesque, 1819)	
bluegill, *Lepomis macrochirus* (Rafinesque, 1819)	
redear sunfish, *Lepomis microlophus* (Gunther, 1859)	
largemouth bass, *Micropterus salmoides* (Lacepede, 1802)	
smallmouth bass, *Micropterus dolomieu* (Lacepede, 1802)	
Percidae - perches	
bigscale logperch, *Percina macrolepida* (Stevenson, 1971)	
Embiotocidae - surfperches	
tule perch, *Hysterocarpus traski* (Gibbons, 1854)	N
All Species:	37
Native Species:	14

upon which proposed restoration objectives are based (see Section 2.3). Restoring these attributes can occur within pre-existing human socioeconomic and infrastructural constraints (e.g., a regulated water supply and land use within the river corridor), as will be shown in section 3.2 regarding flood releases for channel maintenance purposes. Restoring the Attributes will restore and help sustain the myriad of habitats needed to support the native populations that inhabit the Tuolumne River, including habitats essential for salmon production. These Attributes were used to generate the following hydrologic and geomorphic restoration objectives, and allowed us to predict the expected benefits to chinook salmon:

A. <u>Encourage inter-annual and seasonal flow variability.</u>

Considering adaptations in the life history of chinook salmon and other organisms to specific environment conditions will allow us to use these adaptations to our advantage. For example, varying flows during spawning would make the best use of available habitat by distributing fish and encouraging use of all available habitat. Restoring alternate bar sequences would provide quality rearing habitat at a variable range of flows. This restoration strategy is already acknowledged to a limited extent by the use of spring and fall pulse flows for improving outmigration and immigration conditions.

B. <u>Increase the magnitude and frequency of short duration peak flows to initiate bed mobility and localized scour/deposition.</u>

Mobilizing bed surfaces exposes fine sediment for downstream transport and deposition on floodplain surfaces, which, combined with reduced fine sediment supply and increased coarse sediment supply, should reduce fine sediment storage and increase the quality and quantity of spawning and fry rearing habitat.

Combining coarse sediment introduction with channel reconstruction (restoring bedload impedance reaches) will help restore bedload routing downstream, thereby replenishing spawning gravels and gravel bars throughout the gravel-bedded reaches.

Restoring flows of sufficient magnitude and frequency to inundate contemporary and restored floodplain surfaces will deposit fine sediments derived from the low water channel onto floodplain surfaces instead of in spawning gravel, and will encourage floodplain development/processes.

C. <u>Increase the magnitude and frequency of peak flows to initiate bed scour on alluvial deposits along the low water margin to reduce riparian encroachment.</u>

Mobilization of exposed bar surfaces will discourage fossilization of short-term alluvial deposits by reducing riparian encroachment along the low water channel margins, preserving these margins for fry rearing habitat, and maintaining the availability of gravel/cobble storage deposits for eventual downstream routing.

D. <u>Increase coarse sediment input to balance mainstem transport capacity</u>

Restoring coarse sediment supply (particularly spawning gravels between 8 mm to 128 mm) in the gravel-bedded reaches will provide immediate spawning and rearing habitat, and will eventually route downstream to replenish other bars. Introducing clean gravels, combined with reducing fine sediment input, will increase spawning and rearing habitat quality and quantity, increasing juvenile production.

Cleaner alluvium (reduced silt and sand embeddedness) will also improve aquatic invertebrate habitat and prouctivity, the primary food resource for juvenile salmon.

E. <u>Reduce fine sediment input into the river.</u>

Reducing fine sediment input to the river, particularly near La Grange, will improve spawning and rearing habitat conditions, and increase the longevity of gravel quality improvement efforts.

Reducing fine sediment input, combined with high flows that transport and deposit fine sediment onto floodplain surfaces, will reduce instream storage of fine sediment, increase pool depth, improve spawning and rearing habitat quality, and improve salmon emergence and rearing success.

F. Reduce human encroachment onto floodplains to allow limited channel migration.

Restoring channel migration will increase input of large woody debris, adding to the structural complexity of the channel and providing instream cover for salmon.

Restoring channel migration, combined with coarse sediment input, will stimulate formation of gravel bars and floodplains as the channel migrates, creating high quality salmon spawning and rearing habitats.

G. Restore channel morphology, with a bankfull channel and floodway scaled to the expected high flow regime.

A properly-sized bankfull channel will encourage bedload transport by contemporary flood flows, promoting scour and redeposition of on-site alluvial deposits and rejuvenation of downstream sites. This will help the river create and maintain high quality, diverse salmon habitat.

A properly sized bankfull channel will encourage riparian vegetation to establish in natural locations (upper bars and floodplains), and discourage encroachment and fossilization of alluvial deposits along the low water channel margin.

A properly sized bankfull channel and floodway will regulate peak shear stress over a range of flows to reduce risk of catastrophic bed scour and channel degradation (as occurred during the 1997 flood). This will re-establish self-sustaining function to the channel, increasing longevity of salmon habitat restoration efforts (gravel introduction, channel reconstruction).

These recommendations to restore alluvial river integrity are integrated with other management options in developing a restoration vision and strategy for the Tuolumne River corridor that will best restore salmon habitat and population.

Restoring coarse sediment supply, providing periodic high flows capable of routing those sediments, fixing bedload impedance reaches, restoring confinement to the low water channel, and providing a floodway corridor width to allow channel migration, are essential restoration strategies for re-establishing fundamental hydrologic and fluvial processes. These processes form and maintain the natural channel morphology and can do much of the work in restoring or rehabilitating instream and floodplain habitats that sustain healthy populations of aquatic and riparian species.

3. FLUVIAL GEOMORPHIC AND RIPARIAN INVESTIGATIONS

To evaluate the extent that contemporary conditions on the Tuolumne River achieve the Attributes of Alluvial River Ecosystem Integrity (Attributes) presented in Chapter 2 requires some quantification of fluvial and riparian processes on the Tuolumne River. Because this type of information is limited or non-existent, we assessed many of these processes during the development of this Restoration Plan. By comparing the activities needed to achieve the Alluvial River Attributes, with constraints imposed by dams, human encroachment into the floodway, channel degradation from past mining, etc., we can assess whether management actions can restore the Attributes within existing constraints. These institutional constraints usually limit the ultimate extent of restoration, so a scaled-down river, combined with more intensive mechanical management to supplement this shortfall in Attributes (natural processes), may be required.

The objective of this chapter is to quantify and evaluate several of the Attributes. Our evaluation of fluvial processes concentrated on the gravel bedded reach because most of the in-river factors limiting salmon spawning, egg incubation, and rearing are in this reach. The riparian evaluations extend throughout the 52 miles of river. Specific investigations included:

Geomorphology and hydrology

- Bedload impedance reaches
- Bed mobility thresholds
- Bedload transport at Basso Bridge
- Fine sediment (sand) sources
- Evolution of M.J. Ruddy 4-Pumps floodway restoration project and associated channel design considerations
- Flood flow evaluation

Riparian vegitation

- Relate riparian vegetation series to hydrology/channel morphology
- Corridor-wide riparian inventory

3.1. FLUVIAL PROCESSES

3.1.1. Bedload impedance reaches (Attribute #5)

A bedload impedance reach is defined as a location where hydraulic conditions of the contemporary flow regime (generally less than 10,000 cfs) are insufficient to transport coarse bed particles through the reach. These reaches are former instream aggregate extraction and gold dredger pits, where channel width, depth, and slope have been modified to the extent that all bedload in transport from upstream reaches deposits into the pit (Figure 3-1). Reaches downstream of the pit do not have an upstream bedload supply, and bedload is recruited from the bed itself, causing net degradation (lowering) and coarsening (winnowing) of the bed. The entire lower Tuolumne River from La Grange Dam to the confluence of the San Joaquin River was surveyed to identify bedload impedance reaches.

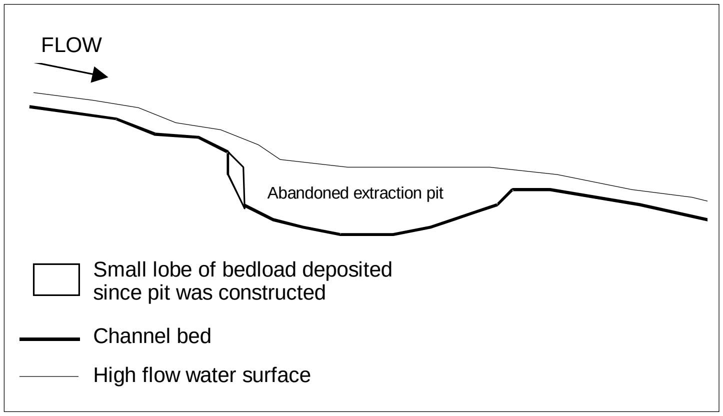


Figure 3-1. Typical bedload impedance reach, where instream aggregate extraction pit traps all bedload transported from upstream reaches.

Re-establishing continuity in coarse bedload transport and routing is the first step to restoring a dynamic river; continuing its transport to downstream reaches maximizes gravel use by "recycling" it over the years as it routes through successive storage sites (bars).

Except for the reach under Old and New Basso Bridges (RM 47.5), the criteria used to identify bedload impedance reaches was (1) the presence of a depositional lobe in a larger pool (Figure 3-1), (2) indications of immobile bed surface, and (3) downstream bed coarsening. At Old Basso Bridge, we measured bedload transport during flows up to 9,400 cfs and found no sediment transport of particles greater than 32 mm. The local surface D_{50} ranged from 50 to 70 mm (visual estimate), and the current high flow regime appears inadequate to mobilize the median grains of the bed surface in this long, flat reach. In most of the bedload impedance reaches, no particles larger than coarse sand (<4 mm) can be transported during high flow events. Table 3-1 lists the bedload impedance reaches found in the gravel-bedded zone of the Tuolumne River.

Table 3-1. Bedload impedance reaches on the Tuolumne River.

River mile	Cause of impedance	Restoration site name
47.2-47.8	Gold Dredging	Basso Bridge Run/Pool
45.0-45.4	Gold Dredging	Special Run Pool 2
43.4-43.8	Gold Dredging	Special Run Pool 3
41.0-41.5	Gold Dredging	Special Run Pool 4
36.7-36.8	Instream aggregate extraction	Clark’s Pool
32.9-33.4	Instream aggregate extraction	Special Run Pool 5
30.15-30.8	Instream aggregate extraction	Special Run Pool 6
27.95-29.5	Instream aggregate extraction	Special Run Pool 7
26.0-27.7	Instream aggregate extraction	Special Run Pool 8
25.8-25.95	Instream aggregate extraction	Special Run Pool 9
25.1-25.4	Instream aggregate extraction	Special Run Pool 10

All of the bedload impedance reaches in Table 3-1, with the exception of SRP 7 and 8, are encompassed in restoration project conceptual designs in Chapter 4. If all these projects were implemented, the ability of the river to route bedload throughout the gravel-bedded reach would be restored if sufficiently high flows are provided to mobilize coarse bedload particles (gravels and cobbles). The discharge needed to mobilize the bed is discussed next.

3.1.2. Bed mobility thresholds (Attribute #3)

Bed mobilization is a fundamental process in gravel bedded rivers. Bed mobilization initiates a variety of alluvial functions, including bedload transport, transporting fine sediment from spawning gravels, particle sorting of the bed material, and spatial sorting of the coarse surface layer. In unimpaired alluvial stream channels, bed mobilization typically begins at or slightly less than bankfull discharge. Observing a threshold of bed mobility is difficult because direct observation of the bed surface is usually not possible during periods of high flow and sediment transport. Therefore, we used two different methods to evaluate bed mobility: 1) tracer rock experiments during a high flow release from NDPP, and 2) bed mobility modeling at hydraulically simple reaches. Tracer rocks are usually painted a florescent color so they can be easily located. Because it is not possible to observe *exactly* when the rocks moved, the tracer rocks were not intended to document an exact threshold discharge; rather, they document if the threshold had been exceeded. If properly installed to accurately represent the adjoining bed particles, tracer rocks provide the most accurate means of predicting mobility thresholds. In the absence of high flows and/or time to wait for a high flow, bed mobility modeling can provide some reasonable threshold estimates for hydraulically simple reaches.

3.1.2.1. Tracer Rocks

As this Restoration Plan was beginning in 1996, flood control releases provided a 5,400 cfs flow to monitor bed mobilization with tracer rocks. Our objective was to evaluate whether 5,400 cfs was transporting gravels and cobbles at varying locations within the gravel bedded reach (RM 25-52). Another objective was to determine the discharge needed to mobilize the D_{84} particle in the M.J. Ruddy Mitigation Project (a spawning riffle reconstructed in 1990). The D_{84} particle represents the framework of the alluvial streambed, so if the D_{84} is mobilized, we can safely conclude that the "bed" is mobilized.

Ideally, tracer rocks that represent the D_{84} size class of the local bed surface would be placed on the bed surface prior to a high flow. Tuolumne River flows were already high when we began work on the fluvial geomorphic components of the Restoration Plan Therefore, we could not go to sample sites and collect particle size distributions prior to the high flow release, nor could tracer rocks be placed properly on the bed prior to the high flow. We chose to use a compromise method of inserting several hundred tracer rocks between 25-150 mm prior to the 5,400 cfs release, but during the 3,600 cfs release (Table 3-2). Tracer rocks were either dropped off a bridge or thrown into the river, instead of traditional hand placement. By doing this, mobility potential was greater for these tracer rocks than native bed particles because the tracer rocks are functionally

Table 3-2. Insertion location, quantity, and size range of tracer rocks on the Tuolumne River.

Site	River Mile	Particle Size	Quantity
Geer Road Bridge (downstream side)	26.0	55-100 mm (2-4 inches)	375
M.J. Ruddy Conveyor Bridge (upstream side)	36.2	50-150 mm (2-6 inches)	300
M.J. Ruddy 4 Pumps Restoration Site (riffle crest above the replaced riffle)	36.7	30-150 mm (1-6 inches)	300
Riffle 4B (left 1/3 of the channel)	48.5	55-100 mm (2-4 inches)	360
New La Grange Bridge (upstream side)	49.9	25-150 mm (1-6 inches)	335
Old La Grange Bridge (upstream side)	50.5	25-150 mm (1-6 inches)	250

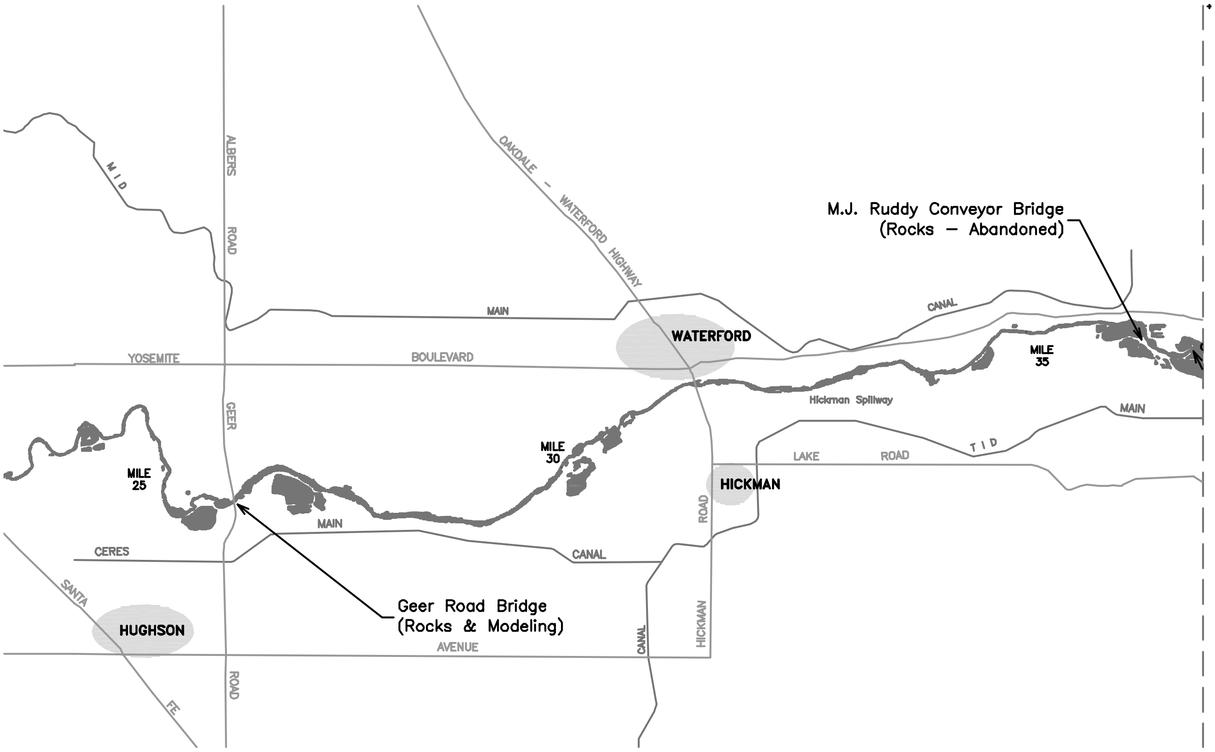


Figure 3-2. Location of tracer rock experiments and bed mobility modeling in the gravel-bedded zone, Tuolumne River.

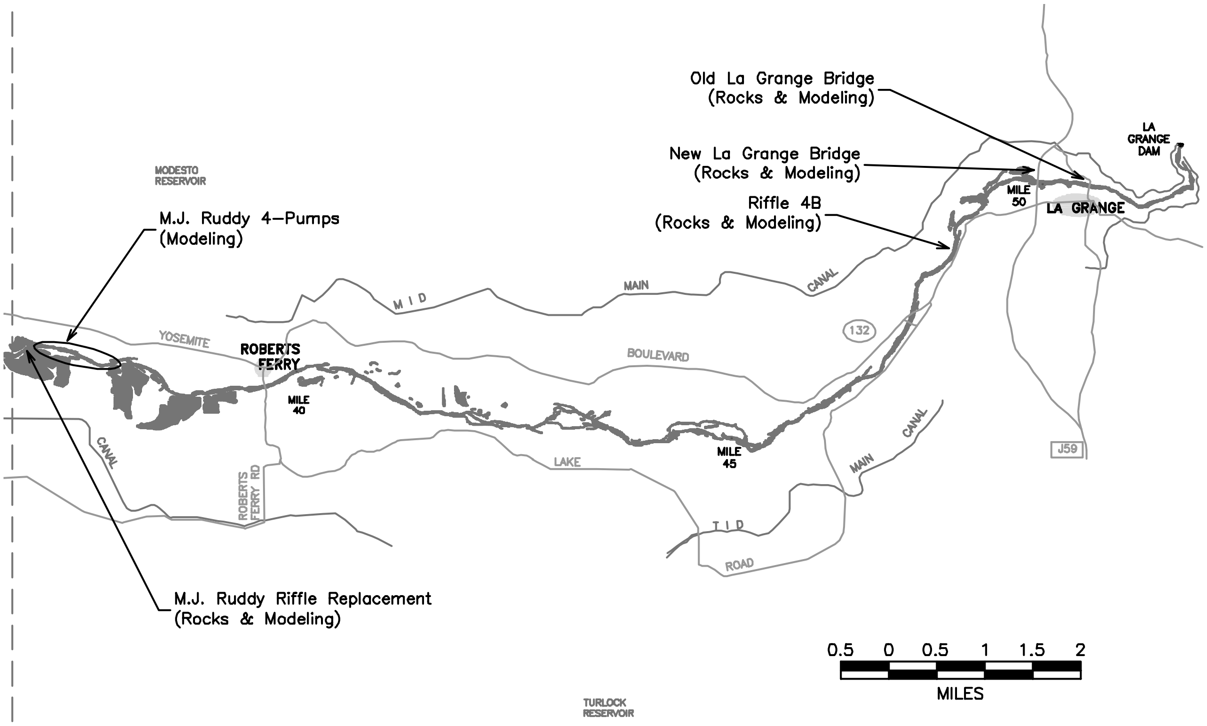
in motion at the time they hit the streambed, and are more likely to be transported downstream than they would be "plucked" from the streambed during natural conditions.

Tracer rocks were inserted at six sites on 23 March 1996 (Figure 3-2, Table 3-2). The daily average discharge for the day was 4,300 cfs at the La Grange gaging station.

Immediately after our rock insertion, the flow increased to 5,300 cfs for several days, then dropped to less than 3,000 cfs for several weeks. Experiments were left in place because higher flows were expected. On May 17th, 1996, flows peaked at an instantaneous discharge of 6,880 cfs (Figure 3-3).

In September, we attempted tracer rock recovery at each site, and measured travel distances, if any. Of all the sample sites, the only location with significant transport distance was Riffle 4B (RM 48.5). At two sites, M.J. Ruddy conveyor bridge and Geer Road Bridge, the tracer rock experiments were discarded. We did not attempt recovery at the M.J. Ruddy conveyor bridge because upon noting the channel conditions at low flow (300 cfs), we realized it was too deep to recover the tracer rocks and was also a poor modeling location. At the Geer Road Bridge, we were unable to relocate any tracer rocks. We are not sure what happened to the tracer rocks, but our bed mobility modeling indicates that the flow at this site did not approach the flow required to move the rocks, and we are virtually certain that the rocks were not transported by the hydrograph shown in Figure 3-3. The loss of these rocks is perhaps due to vandalism, or possibly by subsidence and/or burial under sand.

From these experiments, we concluded that the coarse bed particles in most reaches in the gravel-bedded zone are not significantly mobilized by flows up to 6,880 cfs (Table 3-3). This result was similar to those observed from our bedload transport measurements taken at the Old Basso Bridge (RM 47.4) [see next section]. This is not to say that the bed was static riverwide. Riffle 4B marked rock observations and visual observation at the M.J. Ruddy 4-pumps project (immediately upstream of the M.J. Ruddy Mitigation Project) suggest that 6,880 cfs is capable of mobilizing cobbles and gravels. Possible reasons for this



uniqueness include: 1) the channel morphology was reconstructed at both reaches to a smaller dimension better scaled to the post NDPP high flow regime, and 2) local gravel/cobble supply was larger than adjacent reaches, allowing the river to mobilize those gravels and cobbles. This has important implications for improving river dynamics through channel reconstruction, gravel augmentation, and high flow management prescriptions.

3.1.2.2. Bed mobility models

Bed mobility models were developed for five of the sites where tracer rock experiments were conducted (M.J. Ruddy conveyor bridge site was discarded). Models were calibrated and tested based on our tracer rock observations. The objective of bed mobility modeling is to predict hydraulic conditions (and discharge) that causes incipient mobility of the bed surface. Models are also used to evaluate whether a proposed channel design will facilitate bed surface particles to be mobilized during a bankfull discharge event (Attribute #3).

Modeling cross section sites were selected with hydraulic characteristics that were easily quantified and modeled. Modeling required a variety of field data, including channel geometry obtained from cross section surveys, high water stage and discharge estimates, longitudinal water surface slopes during high flows, and bed surface particle size distributions. With level surveys, we surveyed the channel cross sections to an elevation above our expected high flow elevation and surveyed water surface slopes through the reach during one or more high flows. In some cases, we surveyed flood marks and debris lines instead of actual water surface profiles. We quantified the particle size distribution of the bed within our modeling reaches using modified Wolman pebble counts (Leopold 1970; Wolman 1954). Using the stage, discharge, and slope data, we back-calculated Manning's roughness coefficient (*n*) for each section.

Armed with this hydraulic and particle size data, we applied a tractive force equation, shields equation, and Andrews (1994) bed mobility model to predict the average depth needed to mobilize the D_{84} particle of the bed surface.

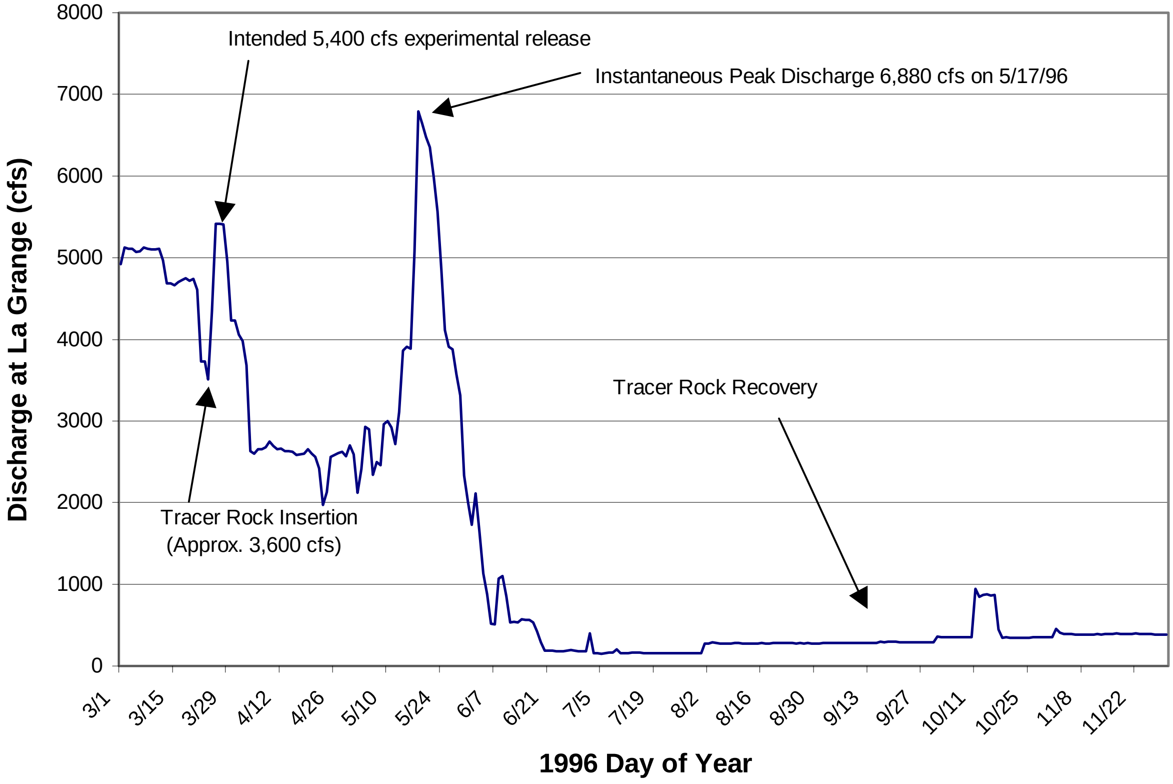


Figure 3-3. Tuolumne River at La Grange streamflows during tracer rock experiments.

Using calibrated Manning's roughness values, we applied Mannings flow resistance equation to predict the discharge at that average depth. Further details of this method can be found in Andrews (1994).

Results of bed mobility modeling suggested that the D_{84} would not be mobilized by flows less than 7,000 to 8,000 cfs (Table 3-3). Our experience comparing tracer rocks with model results on similar gravel bedded rivers showed that D84 Shields parameter of 0.020 to 0.025 caused mobility of the D_{84} particles (McBain & Trush 1997). The modeling predictions tended to support our tracer rock results, but the next step of predicting incipient motion was more problematic. Most modeling sites chosen were where tracer rocks were inserted, and the hydraulics at these locations did not approximate uniform flow as required for simple tractive force equations. This tended to make hydraulic predictions highly variable and less accurate. For example, flow squeezing through bridges is accelerating under the bridge, and decelerating upstream and downstream of the bridge. The simple equations used in this analysis are not meant to be applied under these conditions. The best cross sections to predict incipient motion of the bed were the cross sections at the M.J. Ruddy 4-Pumps Restoration site, because:

- channel reconstruction attempted to size the channel to the post-NDPP flow regime.
- channel reconstruction removed much of the riparian vegetation that fossilizes many reaches of the Tuolumne River.
- high flows from 1993-1996, combined with the coarse sediment supply provided by the restoration activities, allowed the channel to adjust itself.
- hydraulics at most cross sections better approximated uniform flow conditions.

This site also was attractive because previous high flows in 1993-1996 up to 8,500 cfs had caused the channel to adjust, pools to develop, and channel migration to occur. These dynamic channel processes are desired for future restora-

Table 3-3. *Hydraulic characteristics of selected flows observed on the Tuolumne River in WY 1996 and 1997, with tracer rock results.*

River Mile	Site	Cross Section	Discharge (cfs)	Water Surface Slope (ft/ft)	Total Width (ft)	Hydraulic Radius (ft)	Shear Stress (Pa)	D84 (mm)	D84 Shields Parameter	Effective Width (ft)	Effective Hydraulic Radius (ft)	Effective Shear Stress (Pa)	Effective Shields Parameter	Marked Rocks Mobilized?
50.5	*Old LaGrange*	0+29	5,410	0.00080	261	6.4	6.4	98	0.010	158	8.0	19.2	0.012	No
	Bridge		7,600*	0.00080	312	8.8	8.8	98	0.013	158	11.8	28.1	0.018	N/A
			8,700	0.00080	314	7.3	7.3	98	0.011	158	9.7	23.3	0.015	N/A
			60,000	0.00120	484	11.9	11.9	98	0.027	158	16.0	57.3	0.036	N/A
49.9	*New LaGrange*	26+15	5,410	0.00104	311	3.2	10.0	148	0.004	126	5.1	15.9	0.007	No
	Bridge		8,700	0.00104	311	4.2	13.1	148	0.005	126	6.7	20.9	0.009	N/A
			60,000	0.00104	452	12.9	40.2	148	0.017	126	13.4	41.7	0.017	N/A
48.5	*Riffle 4B*	103+55	5,410	0.00133	514	3.0	12.0	124	0.006	149	5.2	20.7	0.010	Partial
36.6-	*M.J. Ruddy*	107+71	5,410	0.00095	205	4.5	12.7	N/A	N/A	82	5.8	16.4	N/A	N/A
37.5	*4 Pumps*	99+14	5,410	0.00140	197	4.2	17.4	N/A	N/A	120	4.8	20.1	N/A	N/A
		94+97	5,410	0.00180	171	5.1	27.5	93	0.018	128	5.0	27.1	0.021	N/A
		88+10	5,410	0.00140	186	4.8	20.4	81	0.016	107	5.9	24.9	0.019	N/A
		79+61	5,410	0.00151	387	3.2	14.6	91	0.010	102	5.3	23.9	0.016	N/A
		67+53	5,410	0.00139	197	5.7	23.6	81	0.018	111	5.0	20.9	0.016	N/A
		60+61	5,410	0.00148	200	5.1	22.5	78	0.018	106	6.4	28.2	0.022	no
26.0	*Geer Road*	0+84	4,000	0.00050	316	5.4	8.0	43	0.012	116	11.2	11.2	0.016	N/A
	Bridge		6,880											no
			7,600	0.00043	400	9.6	12.4	43	0.018	116	11.7	15.0	0.022	N/A

***conditions after 1/3/97 flood event (60,000 cfs peak), which caused significant channel downcutting**

tion efforts. Bed mobility modeling at cross sections 67+53, 88+10, and 94+97 (using a D_{84} Shields parameter of 0.022) predicted discharges of 9,800 cfs, 7,050 cfs, and 8,250 cfs would mobilize the bed surface at this restoration site. The latter two cross sections (88+10 and 94+97) represent those that best approximate uniform flow conditions during high flows. Predictions at these two cross sections should be weighted higher than others. While these incipient flow predictions indicated the bed is mobilized at approximately 7,000 to 8,000 cfs, it is not implied that wholesale bed scour occurs at this flow. These data simply estimate a threshold for D_{84} mobility in the bed surface of riffles. Larger, short-duration discharges are still needed periodically to cause bed scour below the surface layer to remove encroaching vegetation and to rejuvenate alluvial features (see Section 3.2).

3.1.2.3. Management implications

Bed particle mobility and transport are functions of discharge, sediment size, sediment supply, and channel morphology (channel dimensions and slope). The inability of the Tuolumne River to mobilize its bed particles during contemporary high flow events is a result of reduced flow magnitudes and more than 100 years of bedload supply loss and subsequent bed coarsening. We recommend the following remediation:

- Channel restoration projects should construct a narrower bankfull channel that conveys flows between 4,000 cfs and 5,000 cfs and mobilizes the D_{84} of the bed surface. Additionally, flows larger than 5,000 cfs should begin to inundate the floodplain and deposit fine sediments on the floodplain. The floodplain should be sufficiently wide that flows of at least 15,000 cfs do not damage the bankfull channel. The relationship between bankfull channel and bed mobility is important: as flows approach bankfull discharge, the bed particles begin moving, but as flow exceeds bankfull discharge, floodplains begin conveying flow and attenuate the rate of increase in water velocity and shear stress within the bankfull channel. This design reduces the risk of channel damage during large flows, and encourages beneficial processes such as fine sediment deposition, marginal bedload transport, and marginal channel migration.
- Increase the magnitude and variability of high flows during flood control releases (see Section 3.2) to surpass bed mobility thresholds in the restored channel.
- Add large volumes of gravel and cobble (between 8 mm and 128 mm) to encourage bedload transport and deposition. Increasing the bedload supply of these size classes will decrease median particle size, reduce bed coarsening, create salmon habitat, and encourage the channel to adjust its dimensions as needed.

In reaches where channel morphology has not been able to naturally adjust to the post-dam flow regime, the Restoration Plan recommends either active restoration of the site by channel reconstruction, or passive restoration of the site by introducing large volumes of gravel and routing them downstream to allow the channel to self-adjust. The lack of channel morphology self adjustment is only evident in the gravel bedded reach, and gravel introduction and channel restoration should focus entirely in this reach.

3.1.3. Bedload transport

Elimination of coarse sediment supply to the Tuolumne River downstream of La Grange Dam has caused severe channel degradation by scouring he channelbed, banks and gravel bars during high flows, but not redepositing these features because coarse sediment supply from upstream sources is blocked by the NDPP. As predicted in Figure 2-13, this process has cumulatively caused local bed degradation, more extensive bed coarsening, and loss of instream storage of alluvium (active gravel bars). Biota such as salmon and aquatic invertebrates depend on alluvial deposits for habitat; loss of this habitat has reduced the production potential of the river. A preferable management strategy to satisfy Attribute 3 (see Chapter 2) in a regulated system as the Tuolumne River would be to artificially introduce coarse sediment at a size class and rate equivalent to the transport capacity of the high flow regime. For example, if a 14-day flow of 5,000 cfs transported 8,000 yd^3 of coarse sediment from the spawning reaches immediately downstream of La Grange Dam, gravel would be artificially replaced by introducing the appropriate volume immediately downstream of the dam.

Knowing the volume of sediment transported by a flow of given magnitude and duration requires either a large number of cross sections to document change in storage, or a reasonable bedload transport rating curve. Other than sedimentation rates into La Grange Reservoir from 1893-1923, coarse sediment transport data is not available on the Tuolumne River in which any empirical bedload transport relationships could be developed.

The January 1997 flood provided an excellent opportunity to measure sediment transport that was not anticipated during the development of this Restoration Plan. Bedload transport was sampled at two similar discharges: 8,450 cfs on 1/17/97 and 8,200 cfs on 1/30/97.

3.1.3.1. Bedload Sampling

Sampling occurred from the downstream side of the Old Basso Bridge (RM 47.5) using a 6-inch square crane-deployed Helley-Smith bedload sampler (Helley and Smith 1971). Two replicate samples were collected at each sample location along the transect, spaced no more than 20 ft apart over a total effective channel width of 160 feet. At each vertical, the sampler was lowered to the bed surface, allowed to catch bedload in transport for 60 seconds, and then quickly raised to the surface. The bedload sample for each vertical was labeled and bagged for dry sieving in the lab.

Because we were interested in the coarser fractions of bedload transport for evaluating gravel introduction rates, we did not sieve material finer than 0.5 mm. The portion of the sample caught in the pan was simply classed as finer than 0.5 mm and weighed. The remaining sample was sieved into standard size classes, with results presented in two class sizes: (1) coarser than 2 mm, and (2) coarser than 8 mm. These two size classes were chosen because 8 mm was assumed to be the smallest grain size preferable for spawning gravel introduction, and 2 mm is typically the smallest grain size that travels predominately as bedload rather than in suspension. The dry weight of each bedload sample coarser than 8 mm and 2 mm was measured, divided by the time of sample (60 seconds) to compute a unit transport rate for each vertical, and multiplied by the cell width of each vertical to compute a transport rate for each cell. All cells were then summed to compute a total bedload transport rate for particles coarser than 8 mm and 2 mm.

Immediately after the bedload samples were collected, water surface elevations and slopes were surveyed through the sampling cross section to estimate hydraulic properties of the flow. All elevations were based on the USGS benchmark on the southwest bridge abutment (elev=175.61 1929 NGVD). We fitted a bedload transport rating curve to our two data points using Parker's (1979) model to extrapolate to higher discharges.

Both samples at the Old Basso Bridge were near incipient conditions for small gravels but not larger gravels. This minimal gravel transport size is also reflected in the low transport rates (Table 3-4).

The reach under the Old Basso Bridge is the upstream-most bedload impedance reach on the lower Tuolumne River. The low slope at the Old Basso Bridge measurement cross section discourages coarse bedload transport until discharges exceed 8,000 cfs. For example, only 3 percent of the sample material was coarser than 16 mm, and all particles were finer than 32 mm. While the sample location was convenient and the 1997 flood opportunistic for sampling, the Old Basso Bridge does not adequately represent gravel export from the primary spawning reaches upstream because we hypothesize that the

Table 3-4. Summary table of 1997 bedload transport measurements collected at the Old Basso Bridge (RM 47.5).

Date	Discharge (cfs)	Stage (ft)	Slope (ft/ft)	Effective shear stress (Pa)	Bedload transport > 8 mm (tons/day)	Bedload transport > 2 mm (tons/day)
1/4/97	60,000	169.48	0.0013	90.8	Not measured	Not measured
1/17/97	8,450	158.33	0.0005	18.3	39 tons	180 tons
1/30/97	8,200	157.90	0.0005	17.6	30 tons	64 tons

upstream end of this bedload impedance reach traps much of the larger gravels transported from upstream reaches. Except for extremely large floods such as the 1/4/97 flood, spawning gravel-sized particles are probably not transported through the reach. However, our tracer rock observations at Riffle 4B upstream showed that gravel and cobble do begin to mobilize at 6,800 cfs. Riffle 4B is located in a long, straight, rectangular channel reach, such that future bedload measurements and hydraulic calculations could be reasonably made. Additionally, Riffle 4B is immediately upstream of the bedload impedance reach that extends upstream from the Old Basso Bridge; therefore, coarse bedload passing through Riffle 4B better represents coarse bedload export from the primary spawning reach.

3.1.3.2. Management implications

A long-term spawning gravel re-introduction program is essential to improve spawning and rearing habitat in the gravel-bedded reaches below La Grange Dam. Large volumes of gravel introduction will also allow attainment of Attribute #3 (coarse sediment budget), which will encourage the river to re-exhibit dynamic fluvial processes that have been largely missing since the NDPP was completed in 1971. Two reaches should be prioritized for artificial coarse sediment introduction: the reach from La Grange Dam to Basso Bridge (RM 52.0-47.5) and the reach from Peaslee Creek to Waterford (RM 45.5-34.2). A coarse sediment (spawning gravel) management program should be implemented as follows:

1. Artificially introduce a large volume of coarse sediment (cobbles and gravels) to restore coarse sediment storage in the reach between LaGrange Dam and Basso Bridge.
2. Establish a bedload transport measurement station at the downstream end of the respective gravel introduction reach (e.g., near riffle 4B for the La Grange to Basso Bridge reach) to measure the rate of bedload export from the reach. Develop a bedload transport rating curve for particles greater than 8 mm to quantify the volume of bedload exported during high flows for each water year. An alternative method would be to install a large number of cross sections in a particular reach and use them to monitor the volume of coarse alluvial storage loss as it is transported out of a particular reach.
3. Annually introduce spawning gravel volumes equal to that exported by the previous winter high flows. For example, on June 1 of a given year, if 5,500 yd^3 of spawning gravel (greater than 8 mm diameter) was exported from the spawning reach below La Grange Dam from October 1 to June 1, then 5,500 yd^3 would be introduced that summer to replace gravel transported out of the reach. Gravels would be inserted in the reach between La Grange Dam (RM 47.9) and Riffle 5B (RM 47.9).
4. Monitor spawning gravel introduction by establishing 10 to 15 cross sections in alluvial reaches between La Grange Dam (RM 52.0) and Basso Bridge (47.5) to document alluvial deposit evolution (e.g., determine if upstream gravel introduction is replenishing alluvial features). If bedload transport measurements are not done, the number of cross sections would need to be greatly increased. Also, install tracer rocks to measure the downstream distance introduced gravel and cobble are transported each year.

The intent of this method is for gravel introduction to keep pace with gravel export from the spawning reach during high flow events, to maintain the coarse sediment budget (Attribute 5), scour and redeposit alluvial materials (Attributes 3 and 4), and maintains diverse chinook salmon habitat (Attribute 1). Additionally, introducing clean spawning gravel will decrease the percentage of fine sediment in these premium spawning gravels, thus increasing egg-to-emergence success and increasing smolt production in the river. Gravel introduction should be focused in the upstream reach first, due to its importance to salmon spawning and rearing. We also recommend adding gravel to reaches downstream of Basso Bridge, but at the upstream end of reaches with bedload transport continuity (i.e., reaches where bedload impedance has been removed through restoration, such as the upstream end of the Gravel Mining Reach [Reach 5]).

Measuring coarse bedload transport is difficult and expensive. Modeling is less expensive, but fraught with assumptions and inaccuracies that can render results unrealistic. If modeling is pursued, we recommend the approach developed by Wilcock (1997) that fits a bedload transport model to a small number of bedload measurements (usually less than 10). This provides the benefits of economy and accuracy.

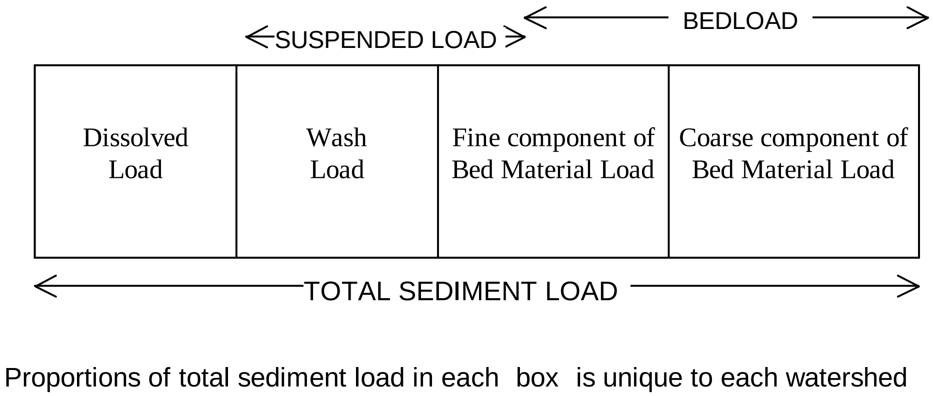


Figure 3-4. Delineation of total sediment load generated from a given watershed. The coarse component of bed material load is typically beneficial to salmon (e.g., spawning gravel, point bars), while the fine component of bed material load is typically harmful to salmon (e.g., clogging of spawning gravels, embeddedness).

Future bedload measurements should not be collected at the Old Basso Bridge, because bedload transport of coarser size fractions does not occur through this reach at flows less than 8,500 cfs. However, tracer rock experiments showed that mobility is beginning to occur at Riffle 4B at 5,400 cfs. We recommend installing a seasonal cableway immediately downstream of Riffle 4B to collect bedload transport measurements that document spawning gravel export rates. Five to ten bedload transport measurements should be collected each year, using a cataraft and crane-deployed 6-inch Helley-Smith sampler to collect samples. At the end of the high flow season, a bedload transport rating curve should be prepared as described by Wilcock (1997) for particles coarser than 8 mm, and using discharge records for the year at the La Grange gaging station, compute annual spawning gravel export volumes annually. Because the reach immediately downstream of La Grange Dam has not had significant coarse sediment supply since 1893, the immediate need for a large quantity of gravel to reverse 100 years of sediment starvation exceeds the need for annual replenishment. We recommend an initial "gravel transfusion," in which a large volume of gravel (> 50,000 yd^3) is placed in the channel throughout the reach to re-create the alluvial deposits eroded over the years. These deposits would also be immediately functional as spawning habitat. Once this transfusion is implemented and alluvial features recreated, the yearly gravel introduction program described above would maintain these features in the future.[4] More detailed methodology, proposed coarse material introduction locations and volumes, and estimated costs for implementation are provided in the "Tuolumne River Sediment Management and Implementation Plan" proposal, in Section 4.5.

3.1.4. Fine sediment sources

Fine sediment is frequently considered an indicator of degraded watersheds and instream habitat conditions, but it is also a normal component of the total sediment yield from all watersheds. Simply defining "fine sediment" is problematic as there is little agreement on which particle size classes should be classified as fine sediment. We use the 8 mm size class to define fine sediment for two reasons: 1) 8 mm is a lower limit for defining coarse sediment, which are transported primarily as bedload; and 2) particles coarser than 8 mm are generally beneficial to salmon habitat, while particle size classes finer than 8 mm are increasingly more deleterious to salmon habitat as the proportion of fine sediment increases. Tappel and Bjornn (1983) related survival to emergence of chinook salmon and steelhead to the percentage of particles finer that 9.5 mm and 0.85 mm, and found that "survival of chinook salmon embryos was more strongly affected by material from 0.85 mm to 9.5 mm in diameter."

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[4] *The CA Department of Fish and Game began implementation of coarse sediment introduction in 1999, with placement of approximately 10,000 yd^3 of gravel to reconstruct riffle R1A, located immediately downstream of the Old La Grange Bridge.*

Fine sediment can be subdivided into the "fine bed material load" (portion of fine sediment load found in the bed surface) and "washload" (the portion of fine sediment load not found in the bed surface) (Figure 3-4). The former, typically between 8 mm and 0.125 mm, is particularly harmful to salmon habitat (e.g., spawning gravels). The latter is finer (typically silts), and on properly functioning rivers usually only deposits on floodplain surfaces that have lower velocities than the main channel. Washload sediment typically has a low frequency of contact with the bed surface within the active channel, and thus typically does not impact salmon habitat. High concentrations of washload may, however, have deleterious effects on fry and juvenile chinook salmon. Washload sediment deposits on floodplain surfaces during floods, benefiting natural riparian regeneration by creating moist seedbeds. Therefore, most effort to reduce fine sediment should focus on sources of fine bed material load (sands). To focus the following discussion, the term "sand" will be used to represent this fine bed material load. Additionally, sources of washload should be de-emphasize, as this component does not typically impair spawning habitat, does not appear to be excessively high on the Tuolumne River, and can greatly improve riparian regeneration in areas where transport and depositional processes are functional.

Regarding fine sediment sources, our objectives were to:

1. Identify point sources of sand causing significant habitat degradation (via large input rates and/or proximity to key salmon habitat).
2. Recommend specific remedial actions to curtail these sand inputs into to the Tuolumne River.

3.1.4.1. Methods and results

Point sources were typically stream channels or large gullies. Non-point sources were usually sheet erosion from orchards or fields and fluvial erosion of bank material. We focused on the stream channels and large gullies because they converted non-point sources in the watershed to point sources inputting sand directly into the Tuolumne River. Additionally, treatment of these point sources is easier than treating non-point sources. There are currently programs and efforts in place to address non-point sources of fine sediment input, such as those programs currently under the purview of the NRCS. We evaluated the gravel bedded reach between La Grange Dam (RM 52.0) and Waterford (RM 31.5) because downstream reaches are naturally transitioning into the sand-bedded zone. The reach from La Grange Dam to Lower Dominici Creek (RM 47.9) was further prioritized because a majority of salmon spawning occurs in this reach. We combined methods to evaluate the relative magnitude of sand sources, with the following methodological progression:

1. Evaluate topographic maps and soil maps to hypothesize significant sand contributors based on drainage area and soil type.
2. Evaluate and compare tributary deltas observed in 1993 aerial photographs, as these photos reflect over 6 years of drought (low mainstem Tuolumne River flows should allow deltas to accumulate).
3. Field reconnaissance to evaluate potential contributors by identifying indicators of relative sand contribution (deltas, sand storage in channel, sand plumes immediately downstream of tributaries) and assessing whether sand is being delivered to the Tuolumne River.

<u>Point sources</u>

The primary factors affecting sand delivery to the Tuolumne River by tributary channels and gullies are watershed size, hydrology, stream channel slope, weathering products and erosivity of underlying soil types, and land use. Boundaries of the individual tributary watersheds were delineated on USGS 1:24,000 scale quadrangles from below La Grange Dam (RM 52.0) to Waterford (RM 31.5), and tributaries were ranked by watershed size to predict potential for sand input. The soil coverage contained within each of the delineated watersheds was then evaluated according to the USDA Soil Conservation Service Soil Coverage Maps (1964) to determine which watersheds contained soils most likely to deliver sand to the Tuolumne River. All watersheds had a large proportion of sandy loams, with lesser amounts of gravelly loams and meikle clays. Additionally, land use on the uplands outside the river corridor was dominated by livestock grazing (nearer to La Grange) and orchards (near Roberts Ferry). Land use along the river corridor was

Table 3-5. Potential fine sediment point sources between RM 32 and RM 52.

RM	Bank	Tributary	Sand input potential
51.3	North	Mill gulch	Low
50.3	North	Gasburg Creek	Large
49.7	North	Morton Gulch	Dissipates on floodplain/terrace
48.9	North	Upper Dominici Creek	Dissipates on floodplain/terrace
47.8	North	Lower Dominici Creek	Moderate
47.0	North	Un-named gulches at Basso Br	Low
45.5	North	Un-named gulch	Dissipates onto floodplain/terrace
45.2	South	Peaslee Creek	Large
44.7	North	Rairden Gulch	Dissipates onto floodplain/terrace
41.0	North	Salter Gulch	Dissipates onto floodplain/terrace
40.5	North	Numerous gullies	Dissipates onto floodplain/terrace
40.2	North	Warner Gulch	Unknown, no delta observed
39.5	North	Roberts Ferry Nut Company gully	Sediment excavated from roadside
38.9	North	Un-named gully	Dissipates onto floodplain/terrace
38.6	North	Un-named gully	Dissipates onto floodplain/terrace
38.2	North	Un-named gully	Low (empties to Ketcham Slough)
37.0	North	Sidecast from orchard road	Low (sheet erosion into river)
35.5	North	Un-named gully	Dissipates onto floodplain/terrace
35.3	North	Road cut erosion	Dissipates onto floodplain/terrace
34	South	Hickman Drain	Low (long, flat backwater)

primarily livestock grazing, row crops, or alfalfa cultivation; however, because these areas were nearly flat (low slope), sand generation within the corridor soils appeared to be very low.

The June 8, 1993 aerial photographs capture the Tuolumne River after a relatively wet water year preceded by five relatively dry water years. Peak discharges at LaGrange were less than 2,000 cfs throughout the five dry years and one wet water year. We hypothesize that the mainstem flows were low enough for significant deltas would persist. Therefore, any resultant tributary deltas in the Tuolumne River visible in the June 8, 1993 air photos could be used as a measure of the relative sediment loading by individual tributaries and gullies to the mainstem over five drought years and one wet year.

Of all the tributaries upstream of Waterford (RM 32.0), only three tributary deltas were conspicuous in the June 8, 1993 air photos: Gasburg Creek (RM 50.3), Lower Dominici Creek (RM 47.8), and Peaslee Creek (RM 45.2). Based on 1997 field observations, we initially estimated average tributary delta depths of 6 feet. Using this approximation, the approximate delta volumes for Gasburg Creek was 380 yd^3, Lower Dominici Creek was 325 yd^3, and Peaslee Creek was 380 yd^3. By assuming a depth of 6 feet, volume estimates are simply surrogates for surface area of delta material. This evaluation showed that these three tributaries were delivering enough fine sediment to the Tuolumne River to be observed on a 1 inch = 500 ft scale aerial photograph. No other tributaries had observable deltas.

In April 1997, all tributaries and gullies within the study area were located and inspected to verify/refute observations from the 1993 aerial photographs, and to evaluate whether tributaries and gullies were delivering their sand load into the Tuolumne River. Most gullies on the valley walls empty onto cultivated fluvial terraces; then cultivation spreads the sediment and prevents it from being delivered directly to the Tuolumne River. Tributaries that deliver fine sediment directly to the Tuolumne River are few (Table 3-5).

To estimate particle size delivered by tributaries and gullies, bulk samples were collected of deposited material at a road cut gully at RM 35.3 and at the Gasburg Creek delta at RM 50.3 (Table 3-5). Sandy loam soils along the Tuolumne River corridor, typical of the road cut gully sample, had 100 percent of particles finer than 2 mm but only 18 percent finer than 0.125 mm. Therefore, soil erosion from hillslopes is predominately sand-sized rather than silt-sized, indicating that hillslope and orchard erosion on uplands can deliver a large proportion of sand to the river. The Gasburg Creek delta sample was coarser, but also had a low percentage of the sample finer than 0.125 mm. The D_{50} (median grain size) was 14 mm, 35% of the sample was finer than 4 mm, and only 1% of the sample was finer than 0.25 mm.

The 1997 flood accessed the New Don Pedro Dam spillway for the first time in its history. Approximately 45,000 cfs flowed down Twin Gulch, causing 25 to 50 feet of incision down to the underlying bedrock, generating a tremendous volume of coarse and fine sediment. Most coarse sediment was deposited in La Grange Reservoir; however, much of the sand was transported through La Grange Reservoir and deposited in the Tuolumne River channel downstream. Three transects were surveyed through Twin Gulch to estimate the volume of topsoil washed downstream, mapping soil/bedrock contact lines and extrapolating this contact across the gulch. We estimate over 200,000 yd^3 of topsoil alone was excavated and delivered to La Grange Reservoir, with much of these finer sediments transported over the dam into the lower Tuolumne River. This fine sediment was primarily sand, which deposited onto floodplain surfaces downstream. Sand deposition on the "floodplains" between La Grange Dam and Basso Bridge (RM 47.5) was up to three feet deep (estimated average depth was approximately 0.5 feet).

The Lower Dominici Creek delta and Gasburg Creek delta were measured to estimate the portion of fine sediment delivered to the Tuolumne River during the January 1997 floods. The existing tributary deltas were assumed to have deposited on the receding limb of the flood. Recent deposition, approximating receding hydrograph limb deposition, was approximately 100 yd^3 for both Lower Dominici Creek and Gasburg Creek. The Gasburg Creek tributary delta was difficult to discern because the tributary sediment deposits were intermixed with sand deposits from prior depositional events. Therefore, these values represented a minimum volume of fine sediment delivery; the actual value is probably much larger. For a rough yardstick, 100 yd^3 is enough fine sediment to cover 325 linear feet of the Tuolumne River low water channel surface to a depth of 1 inch. Actual fine sediment delivery to the Tuolumne River was most likely much larger because the tributary floods preceded the large (60,000 cfs) spill into the Tuolumne River, which most likely eroded much of any delta material deposited in the preceding days.

Rivers naturally sort much of their fine sediment by deposition onto floodplains during high flows. However, in regulated rivers such as the Tuolumne River, sand is often delivered to the mainstem channel by tributaries when the mainstem is not flooding the floodplains. This sand accumulates in the low water channel rather than being deposited on the floodplain. Therefore, chinook salmon habitat is quickly degraded by in-channel sand deposition.

Non-point sources

Non-point sand sources are those that supply sand over an extended area, rather than from a single point. The two primary non-point sand sources are bank erosion and sheet/surface erosion. The number of these non-point sources along the Tuolumne River upstream of Waterford (RM 32) are few. The natural banks along the Tuolumne River are composed of a variety of sediment classes, ranging from clay hardpan to cobbles to sandy loam. Bank erosion is nearly non-existent in the study reach based on sequences of aerial photographs and observations during our river reconnaissance. Channel migration has not occurred since New Don Pedro Dam was built, except near the 7/11 Materials plant site (RM 37.8) and from eroding topsoil dikes throughout the gravel mining reach (RM 35.7 to 39.0). The river was migrating into a cultivated field at the 7/11 Materials plant site, and was rip-rapped in 1997. This rip-rap eliminated this source of fine sediment, but it also eliminated an important source of gravel, which supported extensively used spawning riffles immediately downstream. Bioengineering approaches should be used in the future in place of rip-rap if bank erosion must be eliminated at a certain location. The topsoil dikes through the rest of the reach continue to fail and contribute fine sediment to the channel, but restoration of a wider floodway throughout this reach will eventually replace these dikes with floodplains. The other significant source of fine sediment is infrequent failure of dikes that isolate fine sediment settling ponds at gravel extraction sites. Failure of dikes separating these settling ponds from the bankfull channel results in large volumes of fine sediment input into the river. Additional fine sediment is introduced by the dike failure itself. This occurred at several locations during the 1997 flood and at least one location in 1998. While much of this sediment is probably washload, there is probably a significant volume of sand-sized fine sediment delivered to the Tuolumne River. The floodway restoration project through the gravel mining reach will greatly reduce future fine sediment inputs from these sites.

3.1.4.2. Summary

Of all the gullies and tributaries investigated, Gasburg Creek, Lower Dominici Creek, and Peaslee Creek are the primary sand contributors. Much of the sand originating from Gasburg Creek has historically resulted from sheet runoff from the sand extraction operation immediately north of the Old La Grange Bridge. Gasburg Creek has the highest potential to negatively impact salmon habitat because it delivers sand at the upstream end of the most important reach for salmon production. Remediation for Gasburg Creek is simple; a sedimentation pond near its mouth would prevent nearly all harmful fine sediments (between 0.1 mm and 8 mm) from entering the Tuolumne River (see Sediment Management Plan summary in Chapter 4). Lower Dominici Creek and Peaslee Creek enter the Tuolumne River through incised channels; there is little space available near their mouths to construct a sedimentation pond. There may be some opportunity to construct a head control structure on Lower Dominici Creek immediately upstream of the MID canal, but no site reconnaissance has been conducted. Improved land use practices, particularly along tributary watercourses, could also reduce fine sediment inputs. We recommend spot Helley-Smith bedload measurements with a 3-inch sampler during storm runoff events to better evaluate sand contribution from Lower Dominici Creek before proceeding with remediation.

Constructing floodplains and increasing the magnitude and variability of high flow releases will help mitigate the negative impact of fine sediment delivery from the watershed by encouraging natural deposition on floodplain surfaces. During high flow releases, sediment finer than 1 mm is typically transported in suspension in the mainstem Tuolumne River; fluvial access to floodplain surfaces will cause these sediments to deposit on the floodplains, reducing the proportion depositing in the mainstem channel.

3.1.5. M.J. Ruddy 4-Pumps restoration project evaluation

Between 1992 and 1993, a restoration and mitigation project immediately upstream of the Santa Fe Aggregates (formerly M.J. Ruddy) plant site (RM 36.7 to 37.6) was implemented to reconstruct nearly one mile of channel. The unique feature of this project was that it attempted to reconstruct an alluvial channel sized to the post-dam flow regime, with bankfull channel, floodplains, and terraces. Past restoration activities primarily focused on modifying the active channel (mostly riffle rehabilitation) and planting riparian vegetation. In the summer of 1991, the M.J. Ruddy Mitigation Project reconstructed south bank dikes to increase floodway capacity to 11,000 cfs from RM 36.7 to 37.0, and to provide floodplain and terrace surfaces through this reach. In the summer of 1993, the San Joaquin District of the California Department of Water Resources (DWR) implemented the M.J. Ruddy 4-Pumps Channel Restoration Project. This project constructed a new bankfull channel geometry and planform from RM 36.7 to 37.6, and constructed floodplain and terrace surfaces from RM 37.0 to 37.6. The most significant component of the project was moving the bankfull channel approximately 200 feet north from RM 37.3 to RM 37.6 to reduce erosion into an orchard, and redistributing steep drops in channel elevation back into low gradient pool-riffle sequences to improve chinook salmon habitat.

From the end of construction in 1993 to the beginning of 1997, several high flow events occurred, ranging from 5,000 cfs to 9,000 cfs, which were large enough to cause the channel to adjust its bed and bank morphology. These high flows provided a unique opportunity to evaluate how a reconstructed, appropriately-scaled channel would respond to high flow events. Would the channel adjust and create new pools and riffles? Would the channel migrate and increase sinuosity? Monitoring would also provide information on as-built channel roughness values (Manning's *n*) to apply to other restoration project designs, and to evaluate changes in reach-wide roughness as riparian vegetation matures and channel planform evolves.

A shortcoming of the M.J. Ruddy 4-Pumps Project was that as-built surveys were not conducted, so quantitative comparisons could not be made. Anecdotal descriptions from DWR were relied upon instead. Cross sections, thalweg profiles, and water surface profiles for 250 cfs and 5,410 cfs were surveyed (Figure 3-5). Cross sections (Figures 3-6 to 3-12) were surveyed in the 4-Pumps reach only. After cross sections were input into HEC-RAS, roughness values were adjusted until the predicted 5,410 water surface profile matched the profile measured in the field (Figure 3-13). This calibration discharge was appropriate because flows between 4,500 cfs and 5,500 cfs have been typically used as a desired future design bankfull discharge. Manning's *n* values at 5,410 cfs ranged from 0.027 to 0.029, significantly lower than typical values used by engineers in more vegetated channels (0.035). We expect that over time roughness values will begin to approach 0.035. This evolution in roughness should be incorporated into future channel designs by designing floodplain surfaces based on 5,500 cfs and Manning's *n* value of 0.028, which will result in lower floodplains than if Manning's *n* is 0.035. As vegetation matures and roughness increases, floodplains may begin naturally aggrade from fine sediment deposition.

Particle size was documented with modified Wolman surface pebble counts (Leopold 1970) at many of the cross sections, to evaluate bed mobility thresholds and track changes in particle size over time (Table 3-6, which includes particle size data from other sites). Results of bed mobility modeling are discussed in Section 3.1.2. The as-built sinuosity and longitudinal pool-riffle topography was of particular importance, because our interest was in observing the evolution of pools, riffles, and planform geometry. Aerial photographs taken in June 1993 capture the project being constructed, showing a very slight sinuosity. As-built topographic expression of pools was between 1 and 2 feet (K. Falkenberry-DWR, personal communication). Wet water years in 1995 and 1996 caused several flood control releases of sufficient magnitude to initiate bed mobility (Table 3-7). In the summer of 1996, the 4-Pumps reach had evolved considerably during the high flows of 1995 and 1996, so we surveyed cross sections and thalweg profiles to infer changes (Figure 3-14). No planform evaluation was performed, other than noting that the outsides of many meanders were actively eroding and sinuosity was increasing. Due in part from channel migration, point bar building on the insides of bends was evident (Figures 3-7, 3-10, 3-11, 3-12). The thalweg profile through the 4-Pumps reach showed a regular pool-riffle

Table 3-6. Particle size distribution summary for Tuolumne River pebble counts collected in summer 1996.

River Mile	Cross Section	Location*	Morphology	D84	D50
50.5	0+21	STN 118-203	Run, center of channel	98 mm	58 mm
49.9	26+15	STN 14-140	Riffle, center of channel	148 mm	100 mm
48.5	103+55	Not recorded	Riffle, center of channel	124 mm	86 mm
36.7	60+61	STN 26-132	Riffle, center of channel	78 mm	45 mm
36.8	67+53	STN 52-62	Upper point bar	58 mm	30 mm
		STN 62-75	Point bar	56 mm	22 mm
		STN 75-195	Run, center of channel	81 mm	52 mm
37.0	79+61	STN 63-143, 300-367	Pool/run, left bank point bar & right side of channel	64 mm	36 mm
		STN 143-300	Pool/run, left side of channel	91 mm	62 mm
37.2	88+10	STN 38-180	Pool, center of channel	81 mm	50 mm
37.3	94+97	STN 17-72	Riffle w/median bar, right bank channel	70 mm	40 mm
		STN 79-169	Riffle w/median bar, left bank channel	93 mm	48 mm
26.0	0+94	STN 63-98	Riffle, center of channel	43 mm	25 mm

* Stationing is in feet from left bank cross section pin

Table 3-7. Water years 1995 to 1997 flood histories at the Tuolumne River at La Grange gaging station.

WATER YEAR 1995	**DISCHARGE**
January 30-February 17	4,000 cfs to 5,070 cfs
March 18-19	8,200 cfs
March 25-31	8,000 cfs to 8,300 cfs
April 1-23	6,800 cfs to 8,300 cfs
May 4-June 6	7,600 cfs to 8,700 cfs (peak=9,260 cfs)
July 10-12	8,000 cfs to 8,600 cfs
WATER YEAR 1996	
February 7-March 28	4,500 cfs to 5,500 cfs
May 17-22	6,700 cfs (peak=6,880 cfs)
WATER YEAR 1997	
December 13-21	5,500 cfs to 5,800 cfs
January 3	51,000 cfs (peak=60,000 cfs)
January 11-March 3	7,000 cfs to 9,000 cfs

sequence developing, with ½ wavelengths of approximately 1,000 ft and pool depths of 3 to 4 ft (Figure 3-14). These meander wavelengths match well with predicted values in the literature, and will be useful for designing future restoration projects.

Because the 1997 flood (60,000 cfs) was much larger than the design floodway through this reach (11,000 cfs), dikes failed at RM 38.5, 37.6, 37.1, 36.6, and 35.7-36.2. The large magnitude of the 1997 flood, combined with these local dike failures, caused areas of large bed scour and deposition. In general, bed scour occurred where the river was confined (e.g., RM 37.1 to 37.6). Bed deposition occurred where dikes failed, causing a rapid decrease in sediment transport capacity (e.g., RM 37.0). The process that causes this is vital, as it highlights the importance of functional floodplains and adequate floodway capacity in maintaining channel morphology and salmon habitat.

3.1.6. Channel design considerations

As mentioned briefly, the 1997 flood caused significant damage to the M.J. Ruddy 4-Pumps project. This damage was not just limited to the M.J. Ruddy reach, nor was it limited to 60,000 cfs floods. Dikes in mining reaches commonly failed during flows exceeding 8,000 cfs. Most problems during high flow events are caused by insufficient floodway capacity from aggregate extraction dikes, agricultural encroachment, and riparian encroachment. A classical two stage channel, containing a bankfull channel that conveys most coarse sediment, and a floodplain channel that conveys much of flood flows, provides a dynamic channel and a stable channel (Figure 3-15). The rate of bedload transport is a function of shear stress; the larger the shear stress, the larger the potential for channel damage. The two phased channel provides enough shear stress to transport bedload at marginal rates, but floodplain inundation reduces the rate of increase in shear stress, thereby reducing the risk of significant channel damage. The key is to design the bankfull channel to transport bedload, and design the floodplain width and elevation such that the floodway conveys large discharges without abnormally large velocities and shear stresses.

This importance of a properly sized two-stage channel is best illustrated by an example from the Trinity River. Shear stress distributions measured on a reach of the Trinity River confined by riparian encroachment, and a reach of the Trinity River where the riparian berm was removed and floodplain re-established. In the confined channel, an increase in discharge from 3,000 cfs to 6,500

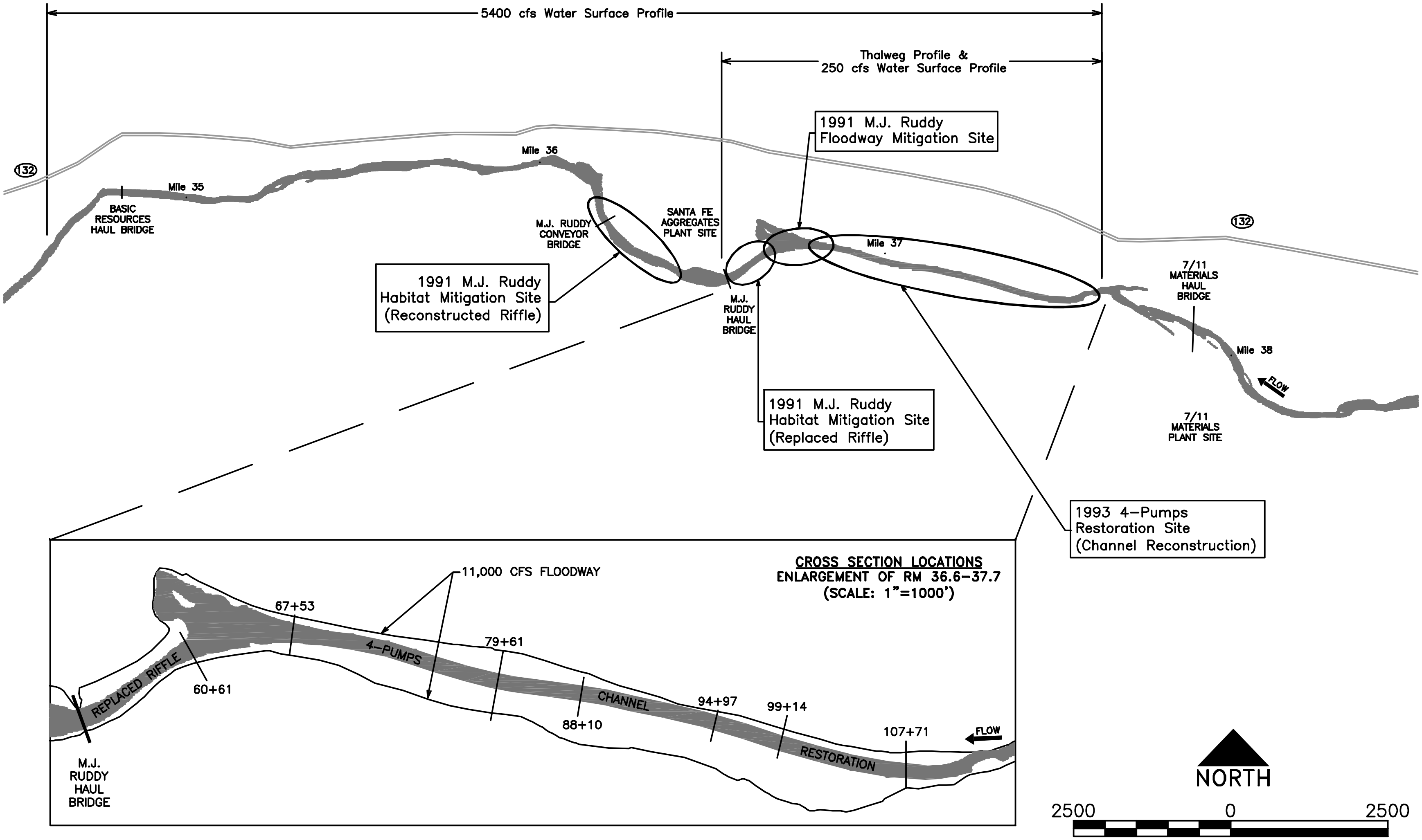


Figure 3-5. M.J. Ruddy reach data collection sites (RM 34.6 to 37.6).

cfs doubles maximum shear stress, and the maximum shear stress remains concentrated in the center of the channel (Figure 3-16). In contrast, in the restored reach, an increase in discharge from 2,500 cfs to 5,100 cfs decreases maximum shear stress slightly, and moves the zone of maximum shear stress onto a point bar surface (Figure 3-17). In the former case, concentrating high shear stress in the center of the channel during large flood events causes significant channel downcutting, whereas shifting shear stress (and therefore scour) onto the point bar surface performs the desired function of preventing riparian encroachment along the low flow channel. Many confined reaches of the Tuolumne River were degraded by the 1997 flood by significant downcutting. Cross sections at the Old La Grange Bridge and New La Grange Bridge document several feet of downcutting (Figures 3-18 and 3-19); other reaches, such as within the M.J. Ruddy 4-Pumps Restoration Project (Figure 3-20), downstream of Roberts Ferry Bridge, and other confined reaches also responded by downcutting. This scoured material was transported downstream until the confinement ended, either by a break in riparian vegetation, valley expansion, or dike failure. In several locations, entire riffles were scoured out (Figure 3-20).

The link between these fluvial processes and salmon habitat can easily be illustrated: 1) channel downcutting in the confined reach removes spawning riffles and bars that provide rearing habitat, 2) scoured material deposits downstream, raising the riffle crest elevation, creating a long backwater upstream and a very steep riffle downstream (Figure 3-21). Not only is habitat lost by scouring, but deposition increases riffle slope to the point where velocities exceed suitable ranges and reduce habitat. This is partially illustrated at the M.J. Ruddy 4-Pumps Restoration Project, where Riffle 34A was scoured away (Figure 3-20). Therefore, the key to creating and maintaining a healthy Tuolumne River channel and associated habitat is to increase floodway capacity, and (re)construct properly sized two-stage channels that convey flow and coarse sediment, but also safely convey large floods of at least 15,000 cfs. A vegetated floodway 500 feet wide in the gravel bedded reaches should safely convey 15,000 cfs and provide enough room for some channel migration. Increasing the floodway capacity will also increase the ability of the flood management system to better avoid extreme floods as experienced in 1997. Additionally, increasing flows in the 8,000 cfs to 15,000 cfs range will greatly benefit the Tuolumne River channel and habitat by mobilizing the bed surface, transporting fine sediment, discouraging future riparian encroachment, and allowing the channel to adjust its dimensions if necessary. The opportunity to increase the frequency of high flows in the 8,000 cfs to 15,000 cfs range in a way that avoids impacts to water supply and minimizes impacts to power generation is evaluated in the following section.

3.2. FLOOD FLOW EVALUATION

Floods are natural events within river corridors. Floods are also negatively perceived by the public. However, as scientific understanding of river ecosystem function has developed, it has become apparent that floods are actually crucial to a healthy river ecosystem. As discussed in Chapter 2, floods are responsible for attaining several Attributes of Alluvial River Integrity. While some restoration programs acknowledge the need for restoring floods (e.g., flushing flows, channel maintenance flows), recommending and implementing managed high flows have been limited. The 1996 flood release on the Colorado River from Glen Canyon Dam is perhaps the most noteworthy. Several recommendations are provided for improving Tuolumne River flood release management that could greatly aid in rehabilitating and maintaining dynamic riverine habitats. These recommendations are based on quantifying thresholds for important fluvial processes (e.g., bed mobility, bedload transport rates, gravel introduction rates).

3.2.1. Fluvial geomorphic thresholds

Recalling that frequent bed surface mobilization is a fundamental attribute of healthy alluvial rivers (Attribute No. 3), an important restoration objective is to improve the ability of the river to mobilize its bed surface. The term "general bed mobility" is used to describe mobilization of the D84 size class over most portions of the channelbed. Bed mobilization typically occurs in naturally functioning alluvial rivers at, or slightly less than, bankfull discharge (Andrews 1983, Leopold 1994). Bankfull discharge typically ranges

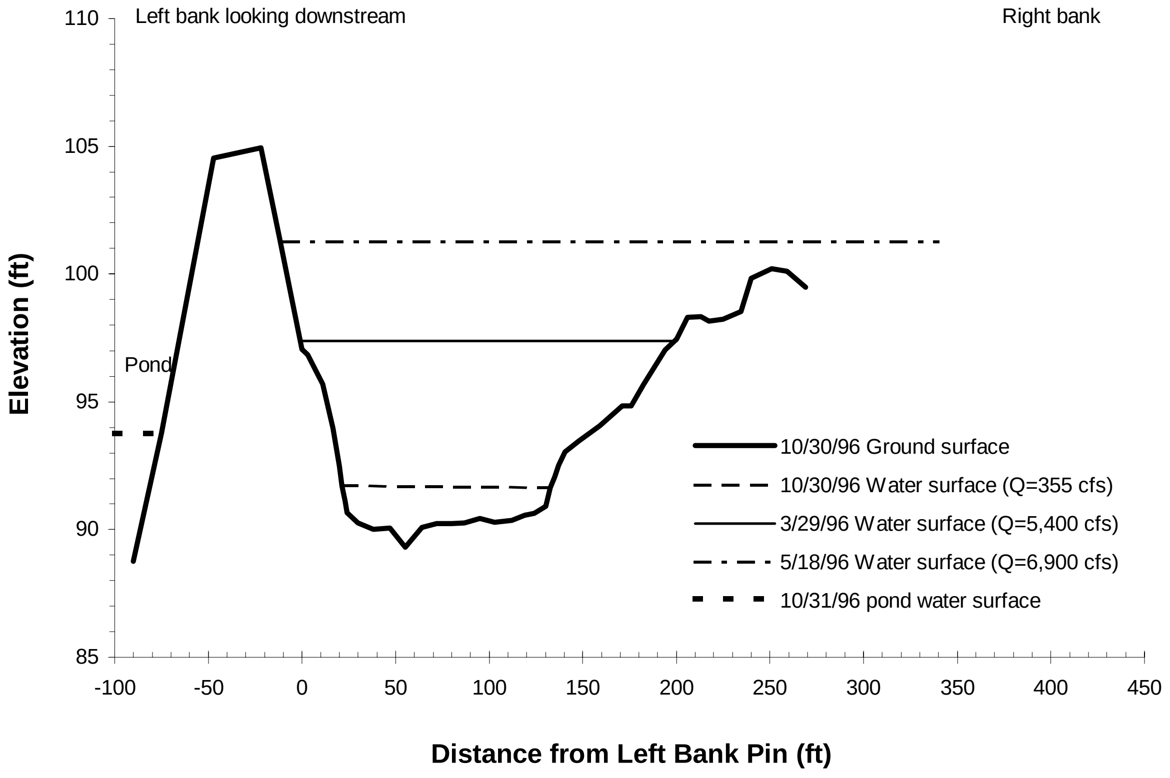


Figure 3-6. M.J. Ruddy mitigation site, cross section 60+61.

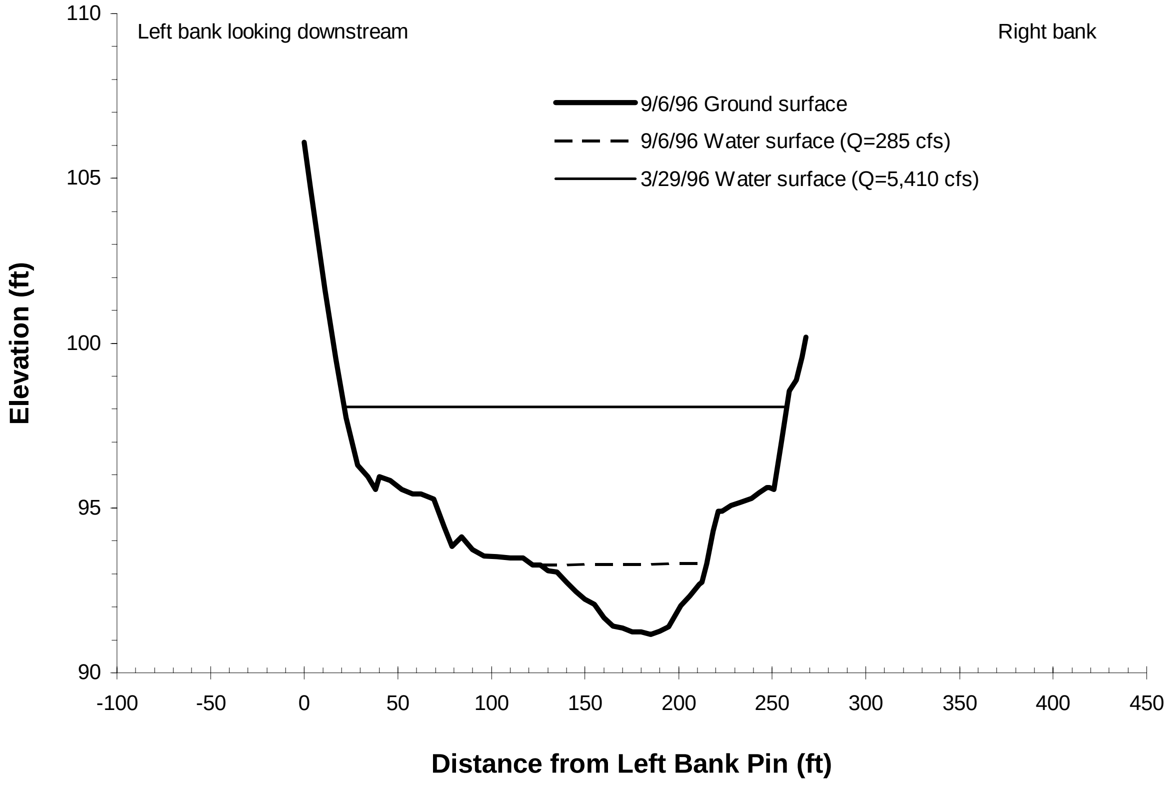


Figure 3-7. M.J. Ruddy 4 Pumps site, cross section 67+53.

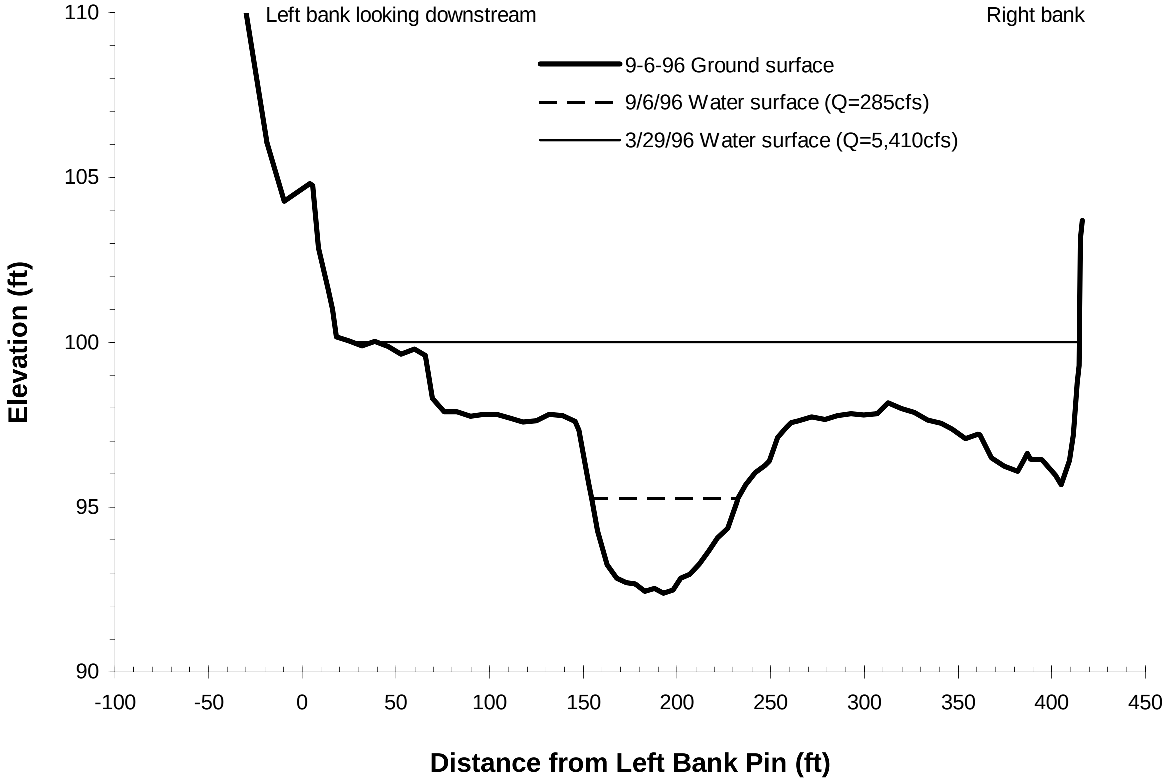


Figure 3-8. M. J. Ruddy 4 Pumps site, cross section 79+61.

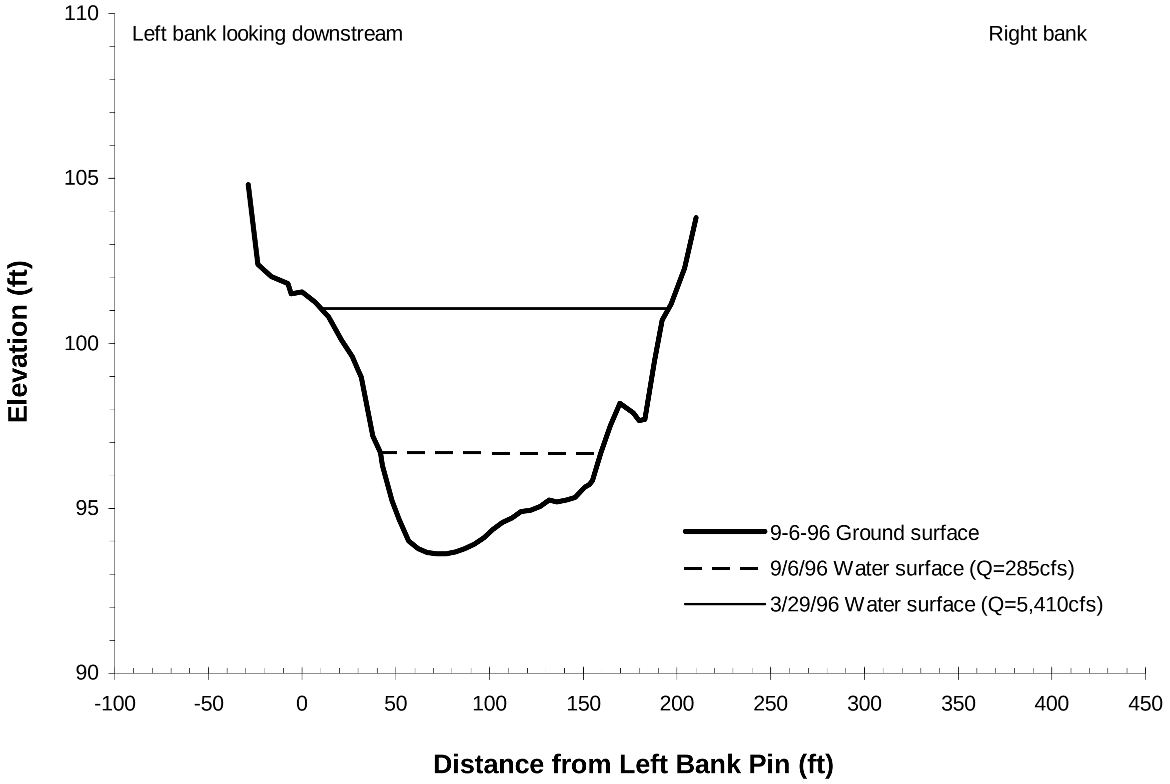


Figure 3-9. M. J. Ruddy 4 Pumps site, cross section 88+10.

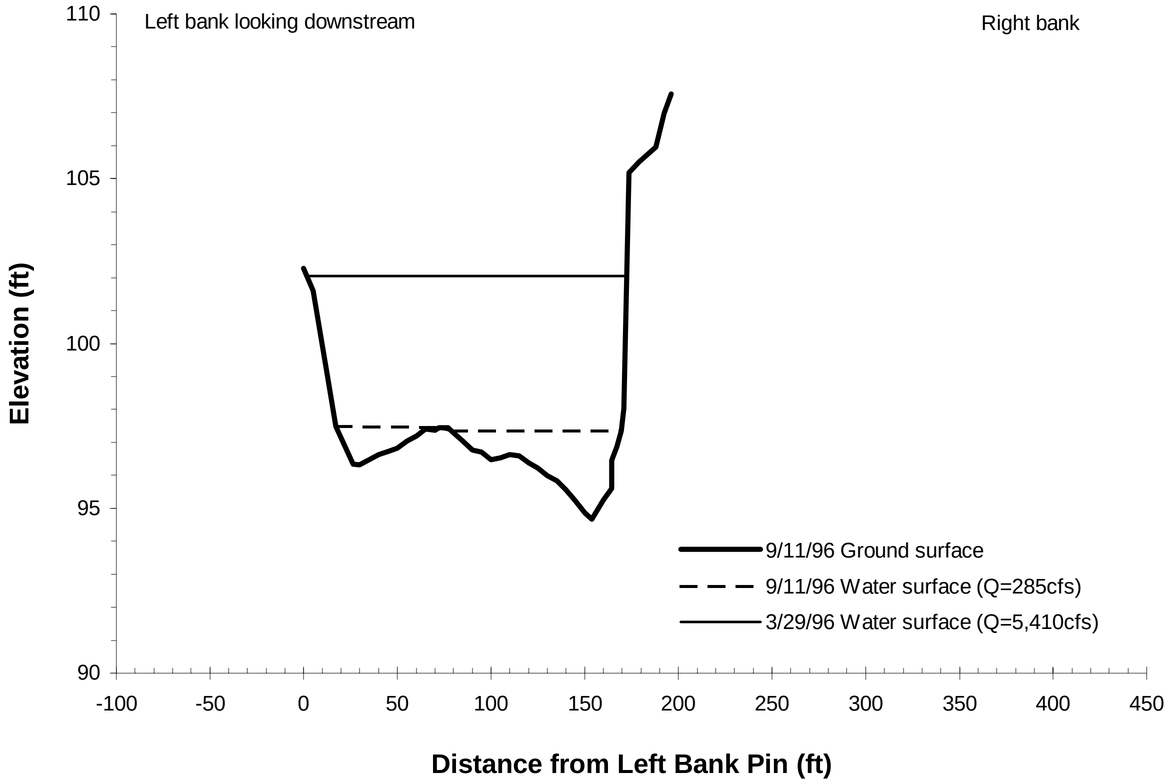


Figure 3-10. M. J. Ruddy 4 Pumps site, cross section 94+97.

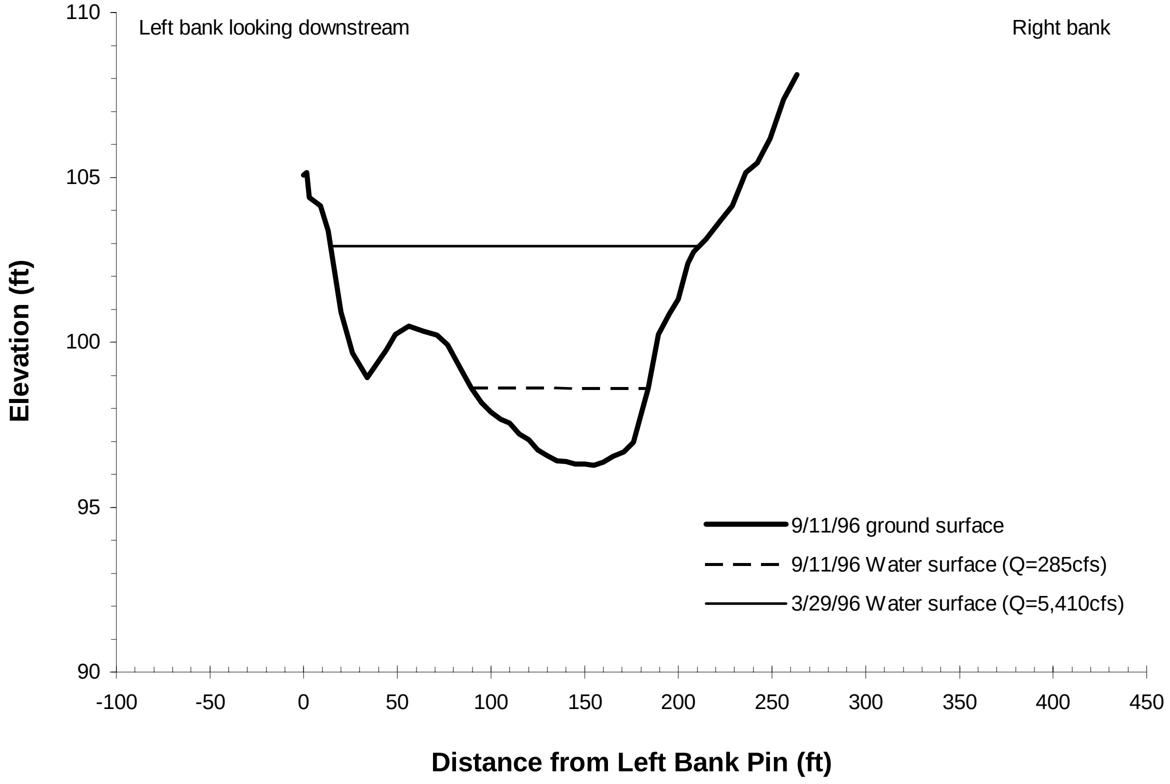


Figure 3-11. M. J. Ruddy 4 Pumps site, cross section 99+14.

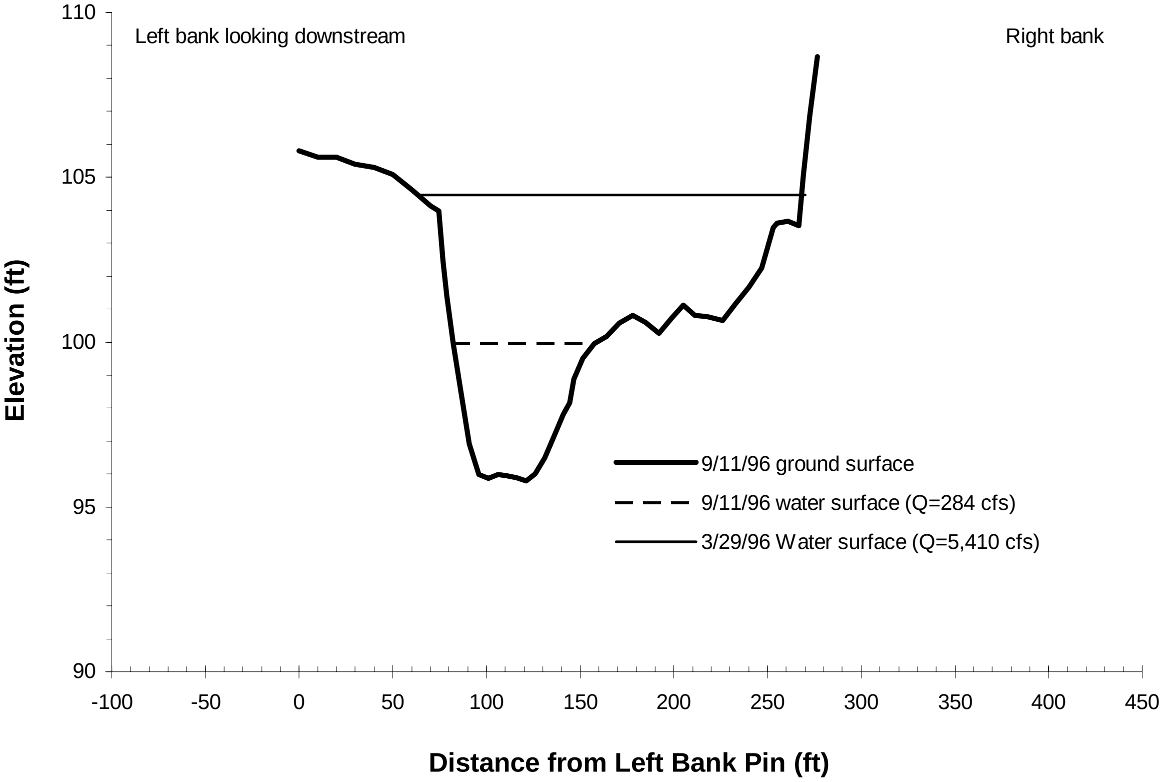


Figure 3-12. M. J. Ruddy 4 Pumps site, cross section 107+71.

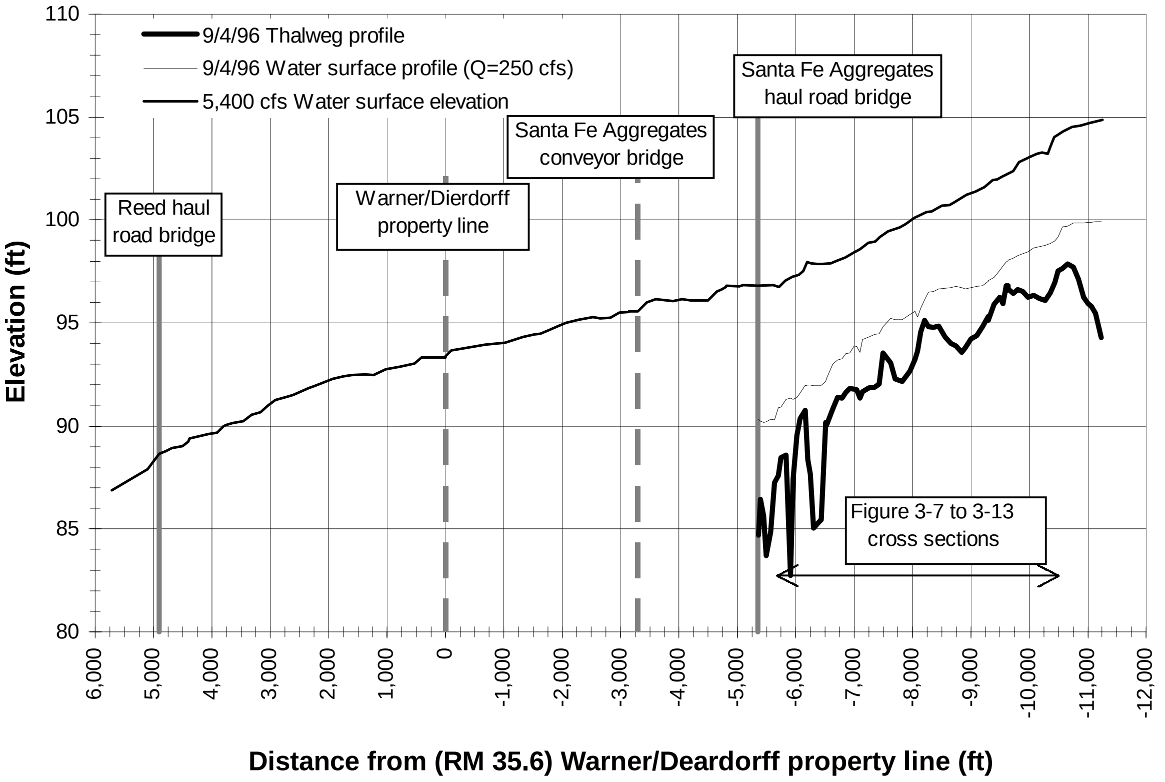


Figure 3-13. Tuolumne River 1996 longitudinal profiles from river mile 34.6 to 37.8 (Section 24 and 32 T.3S., R.12 E.).

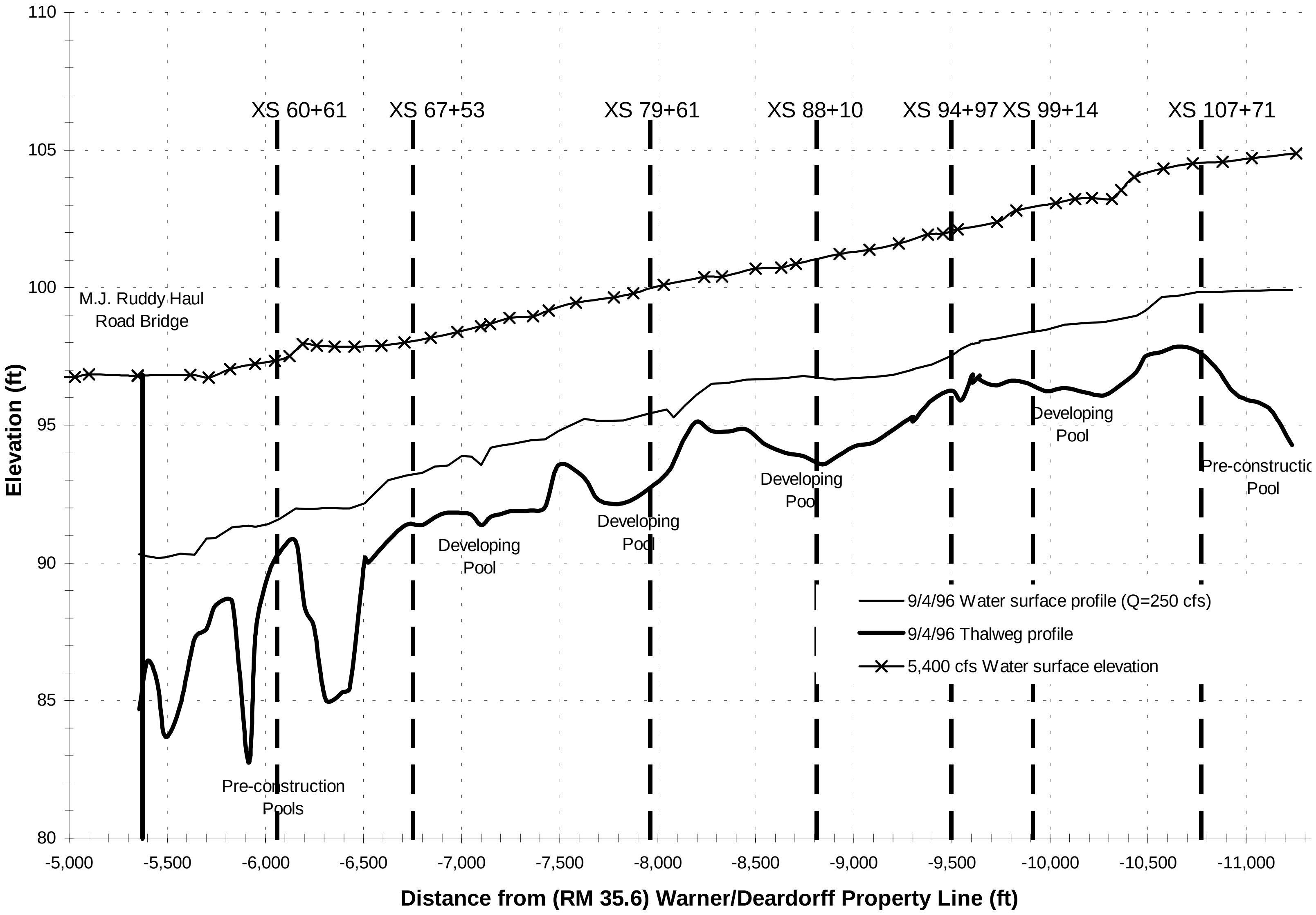


Figure 3-14. Thalweg and water surface profiles through the M. J. Ruddy 4-Pumps restoration site, river mile 36.8 to 37.7 (Section 29 and 30 T.3S., R.12 E.).

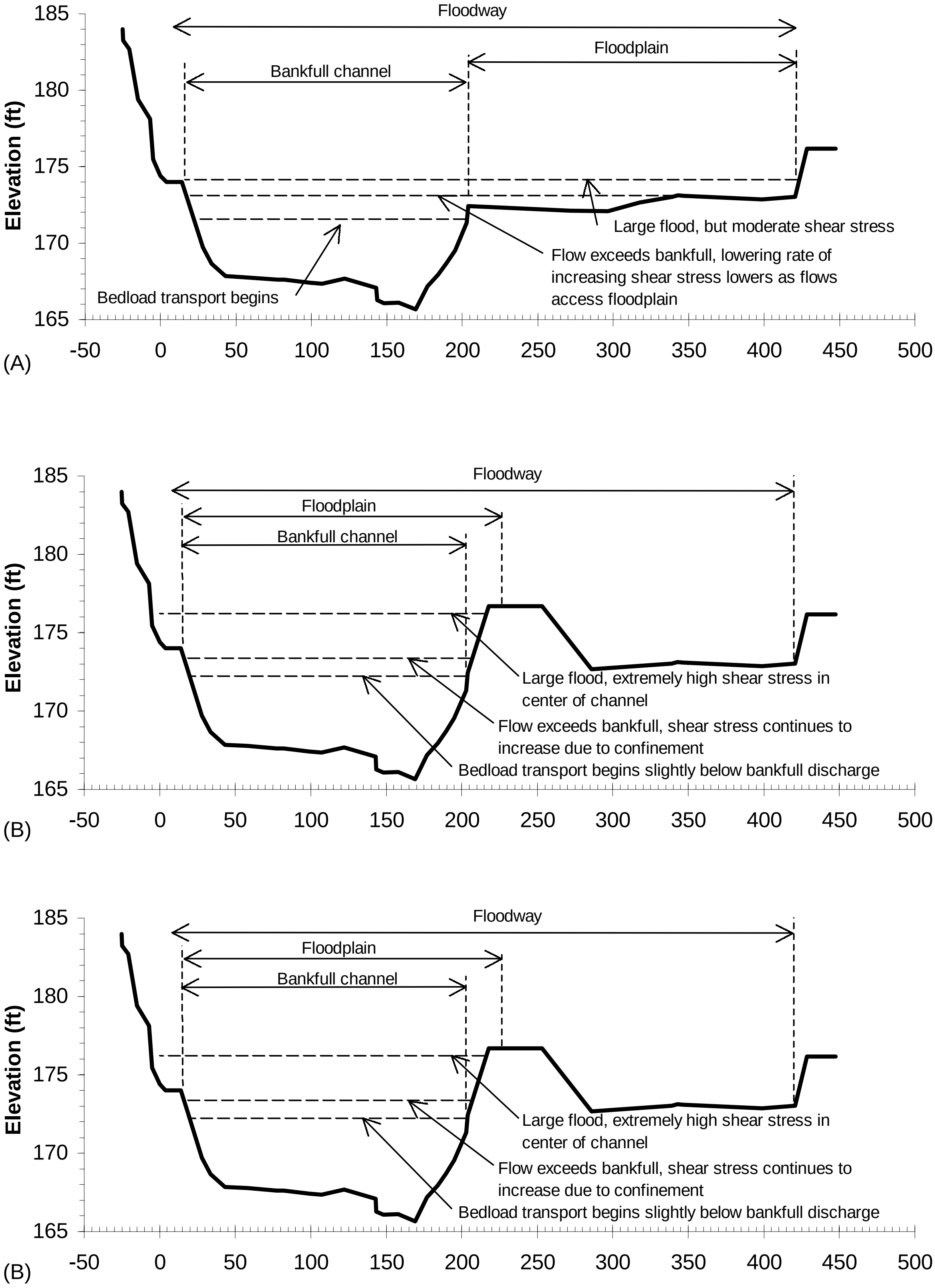


Figure 3-15. Natural two-stage channel (A), and impact of encroached (riparian, urban, agricultural, and/or aggregate extraction) channel, (B) and unconfined channel, and (C) on shear stress and bedload transport.

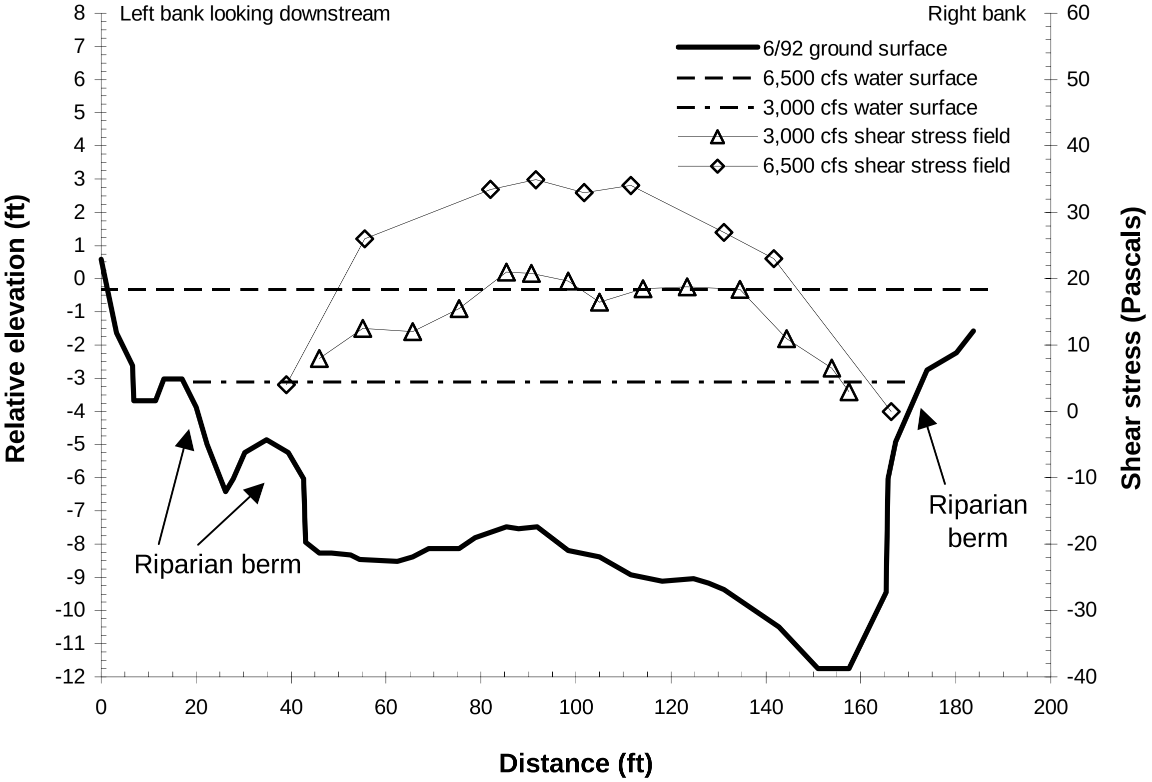


Figure 3-16. Shear stress distribution on Trinity River cross sections confined by riparian encroachment.

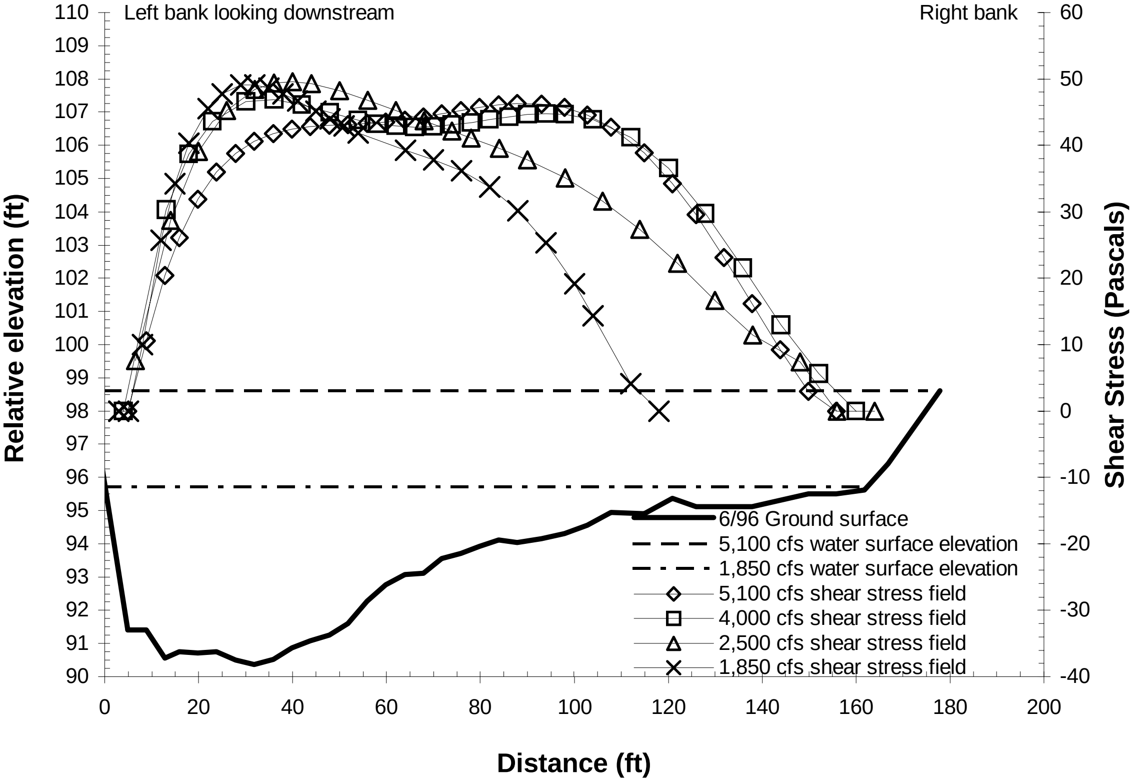


Figure 3-17. Shear stress distribution on Trinity River cross sections in unconfined restored reaches.

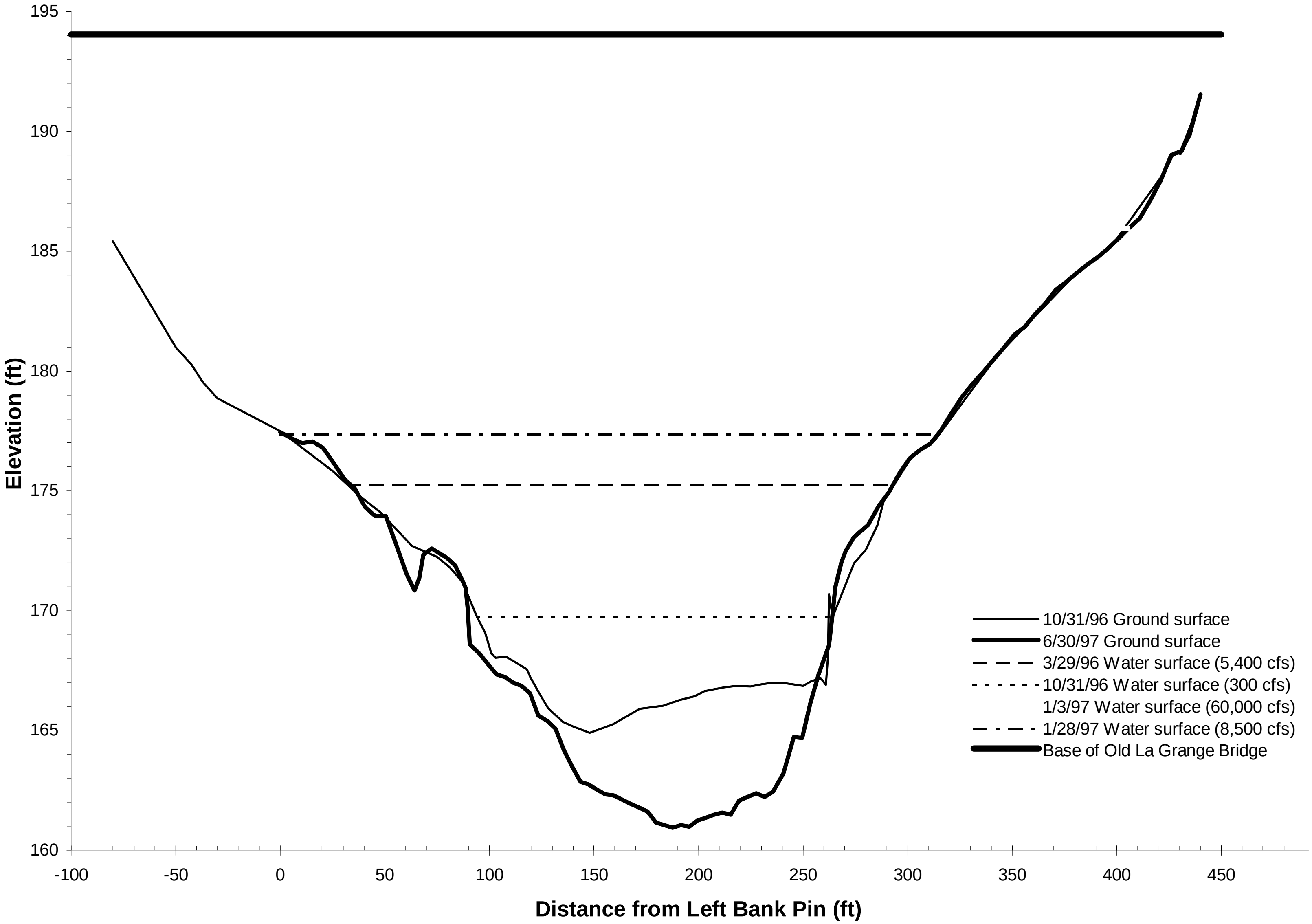


Figure 3-18. Cross section at Old La Grange Bridge (RM 50.5) showing channel downcutting resulting from January 1997 flood (60,000 cfs).

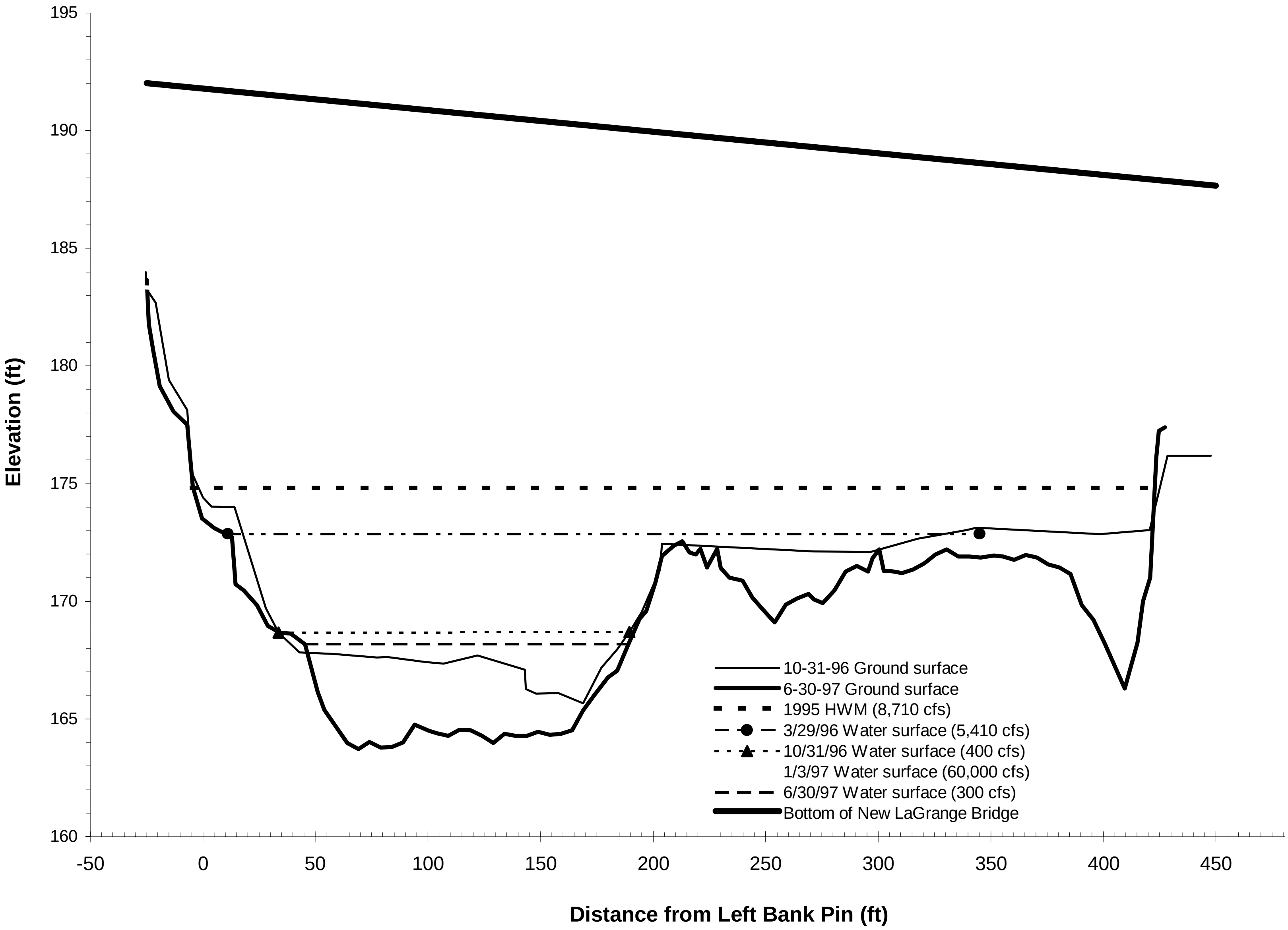


Figure 3-19. Cross section at New La Grange Birdge (RM 49.9) showing channel downcutting resulting form January 1997 flood (60,000 cfs).

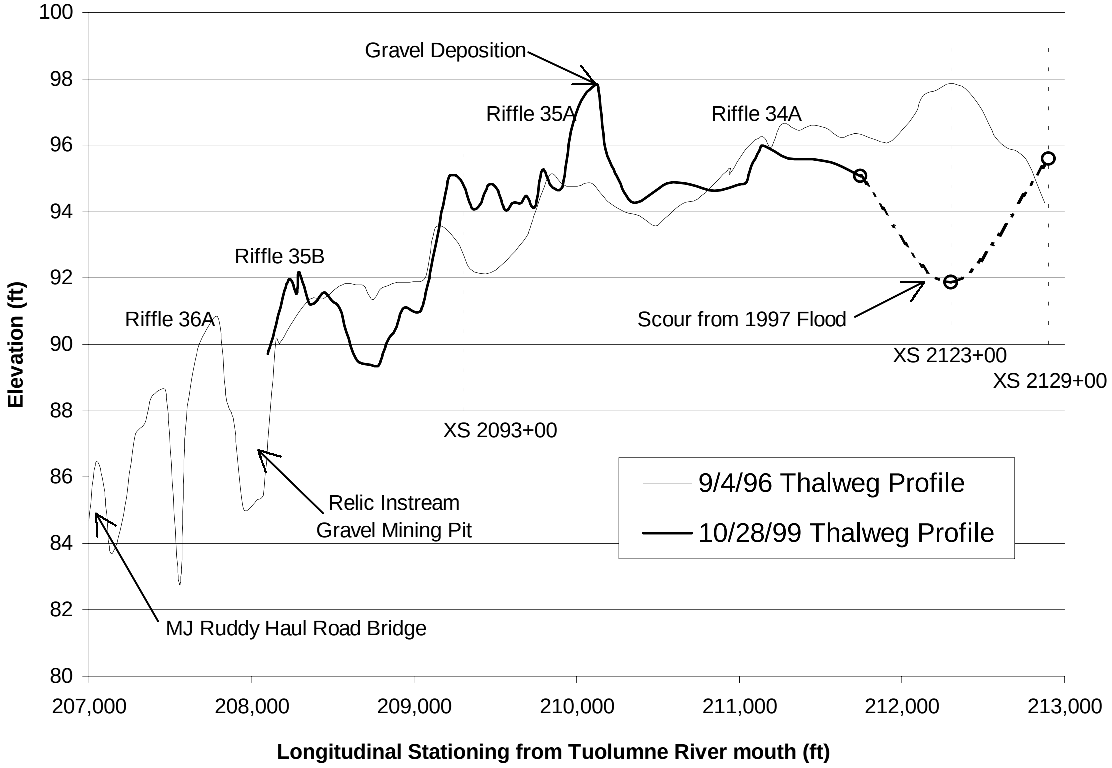


Figure 3-20. Longitudinal profiles of Tuolumne River downstream of Old Basso Bridge before and after the January 1997 flood (60,000 cfs), illustrating scour and loss of riffles due to channel confinement.

between the 1.5 to 2.5-year recurrence flood on an annual maximum flood frequency curve. This relationship allows us to initially estimate a bed mobilization discharge based solely on a flood frequency curve. The bankfull discharge also approximates the discharge class responsible for channel sizing, so any change in bankfull discharge will change the ability of the river to form and maintain its channel. The 1.5-year recurrence flood at the La Grange gaging station (RM 51.6) decreased from 8,600 cfs to 3,000 cfs as a result of the New Don Pedro Project (NDPP). For the post-NDPP 1.5-year flood to continue mobilizing the bed surface, channel size (cross sectional area) and/or particle size must decrease commensurate with the reduction in the channel forming flood. Bed mobility experiments, bed mobility modeling, and bedload transport sampling indicates that flows in excess of 7,000 cfs to 8,000 cfs are presently required to begin general mobilization of the bed surface. This threshold bed mobilization discharge is much larger than the post-dam 1.5 to 2.5 year flood for two reasons: (1) the present channel is a relic of the pre-NDPP channel morphology, scaled to the larger pre-NDPP high flow regime, and (2) the bed has most likely coarsened due to coarse sediment deficit, raising the flow threshold necessary to mobilize the bed particles. Properly sizing future channel restoration projects and artificially restoring coarse sediment supply by introducing large volumes of coarse sediment (between 8 mm and 128 mm), should provide a more natural frequency of bed mobilization.

Another important threshold is the discharge that begins to inundate contemporary floodplains. Unfortunately, the reduction in flows, extensive channel disturbance, and low sediment supply have prevented any distinct post-NDPP floodplains to form, so this threshold could not be evaluated.

Other thresholds, such as bed scour and channel migration, were not quantified during this study. Observations at the M.J. Ruddy 4-Pumps project during 1995-96 showed that slow channel migration was occurring during flows ranging

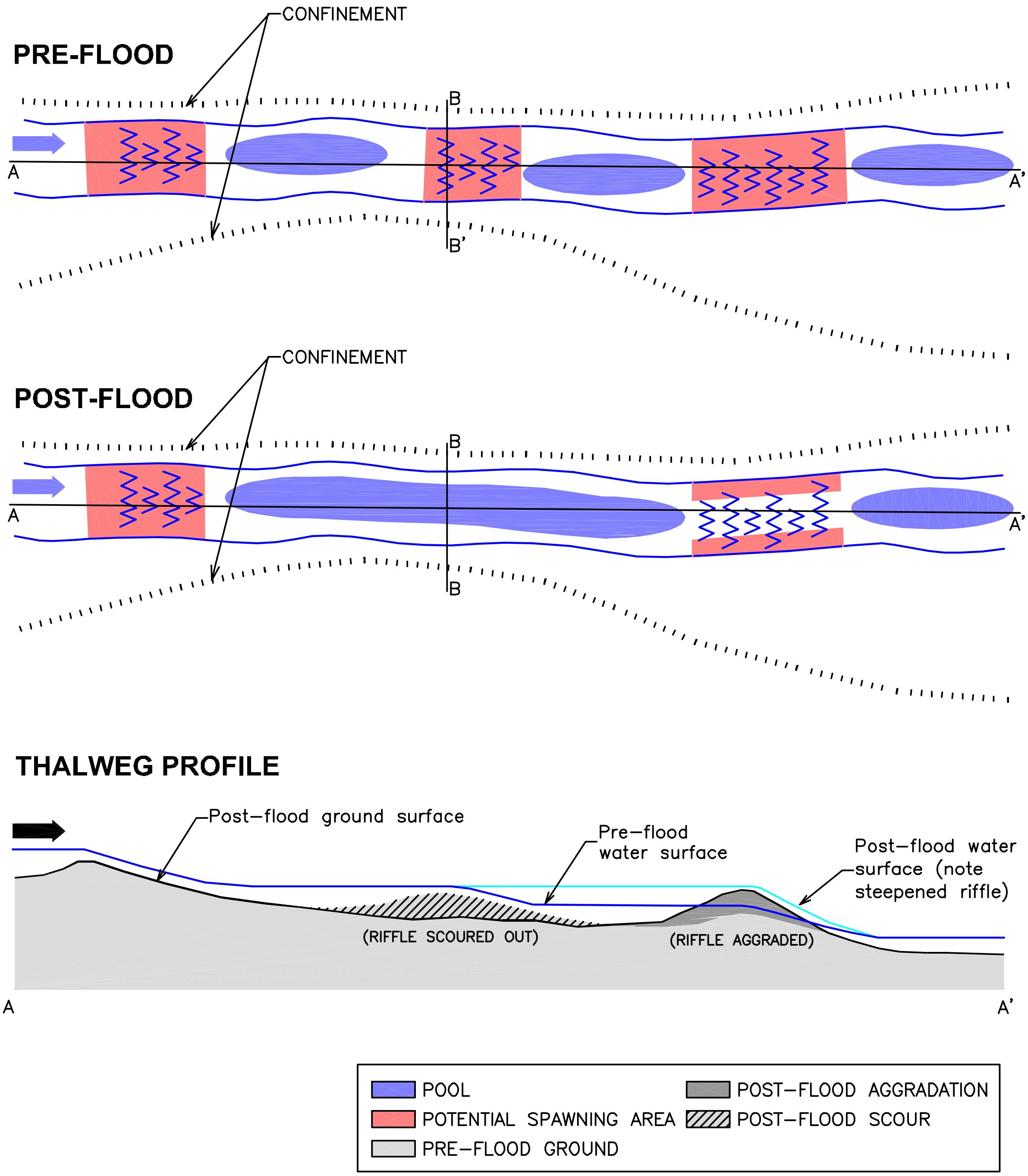


Figure 3-21. Conceptual evolution of pool-riffle morphology in confined reaches of the Tuolumne River.

from 5,400 cfs to 8,500 cfs; however, because as-built (post-construction) conditions were not surveyed, the channel migration rate could not be quantified.

3.2.2. Feasibility of using flood management or power peaking releases to improve fluvial processes

A healthy river has both high flows and low flows (Attribute 2). Sustained steady summer baseflows encourage riparian initiation. Without subsequent high flows, this vegetation will mature and fossilize the channel as observed on the Stanislaus River, Trinity River, Clear Creek, upper Sacramento River, and others. A range of flood magnitudes provides varying degrees of fluvial processes, exceeds important geomorphic thresholds, and creates diverse, high quality salmon habitat. While post-NDPP flood control releases on the Tuolumne River have helped minimize the degree of riparian encroachment and channel fossilization compared to other regulated rivers within the Central Valley region, fluvial processes and habitat within the Tuolumne River could greatly benefit by increasing the magnitude and frequency of high flows. One important opportunity to improve the magnitude and frequency of Tuolumne River high flows is to incorporate geomorphic objectives in flood control releases.

Moderate-to-high flows on the Tuolumne River are periodically released for three purposes: low magnitude (<3,000 cfs) pulse flows for adult salmon attraction in the fall and smolt outmigration in the spring, moderate magnitude winter power generation (up to 5,400 cfs), and flood control releases. Pulse flows have always been below the threshold for mobilizing the bed surface, and have had limited geomorphic use to date. However, pulse flows in wetter water years can be adjusted to begin surpassing some geomorphic thresholds. Power generation and flood control releases, however, are sometimes large enough to cause bed mobilization. By modifying periods of long-duration, moderate-magnitude flood control releases to include a short-duration, large-magnitude flow component, additional geomorphic thresholds can be achieved. The magnitude of this high flow should be greater than the bed mobility threshold (8,000 cfs), and should increase in magnitude with wet water years (as typically occurs in the unimpaired flow regime). This variation in high flow magnitude will mobilize different alluvial deposits (pool tails, riffles, lee deposits, etc) and create diverse patches of particle sizes throughout a reach. Because these alluvial deposits create salmon habitat, varying mobilization patterns will encourage diverse and dynamic chinook salmon habitat.

We recommend evaluating opportunities to revise operating criteria during flood control release periods (typically in wet water years) to provide short duration, larger magnitude pulse flows. These larger magnitude releases should not interfere with flood control efforts specific to the Tuolumne River (actually should help decrease reservoir elevation more rapidly), but downstream human encroachment constraints, inadequate dikes, and other tributary flood routing (San Joaquin, Merced, Stanislaus rivers) must be considered. Furthermore, instream release volumes need not change from FSA values, but should simply redistribute a short portion of the flood control release to improve fluvial processes. We recommend that magnitudes vary from year to year from 9,000 cfs to 15,000 cfs to provide fluvial geomorphic and flood management benefits. This range of flows, combined with channel rehabilitation activities and a gravel augmentation program, will facilitate recovery of instream salmon habitat and channel dimensions. Ideally, flood magnitudes should correspond basin water yield (i.e., the wetter the water year, the larger the flood magnitude).

We evaluated annual hydrographs from 1970 to 1996 to illustrate the potential for increasing flood control releases (Table 3-8, Figures 3-22 to 3-29). Maximum power generation occurs when New Don Pedro releases are about 5,400 cfs (depending on reservoir elevation). This evaluation suggests, with the possible exception of WY1984 and WY1996, that a short duration, larger magnitude managed high flow could have been released in all flood control years (Figures 3-22 to 3-29) without significantly reducing power generation. General guidelines for managed high flow releases include:

- High flow releases greater than 9,000 cfs should ideally occur after mid-February to reduce the potential for scour-induced mortality to incubating salmonid eggs.

Table 3-8. Wy 1970-1997 instream releases, and potential modifications to peak flows to improve geomorphic processes.

<==OBSERVED						RECOMMENDED==>		
Water Year	Maximum daily average discharge (cfs)	Number of days flows >3,000 cfs	Number of days flows >5,500 cfs	Instream release (Acre-ft)	Rank of instream release volume	Recommended additional peak flow (cfs)	Duration of peak flow (days)	Additional water volume bypassing power plant (Acre-ft)*
1970	7,000	20	13	729,000	9	8,000	3	22,000
1971	2,490	0	0	346,000				0
1972	1,450	0	0	164,000				0
1973	1,370	0	0	165,000				0
1974	1,940	0	0	376,000				0
1975	3,080	2	0	561,000				0
1976	2,730	0	0	360,000				0
1977	224	0	0	67,000				0
1978	4,570	10	0	292,000		5,500	3	0
1979	3,650	36	0	657,000	10	5,500	3	0
1980	7,280	76	38	1,493,000	5	10,000	2	44,000
1981	2,980	0	0	441,000				0
1982	8,150	113	49	1,718,000	4	10,000	2	44,000
1983	10,400	288	118	3,465,000	1	12,000	1	69,000
1984	8,010	130	14	1,376,000	6	10,000	2	44,000
1985	2,820	0	0	376,000				0
1986	6,870	68	37	1,134,000	8	10,000	2	44,000
1987	2,980	0	0	283,000				0
1988	588	0	0	78,000				0
1989	767	0	0	61,000				0
1990	861	0	0	85,000				0
1991	1,190	0	0	83,000				0
1992	1,150	0	0	81,000				0
1993	1,760	0	0	241,000				0
1994	3,080	1	0	187,000				0
1995	8,710	151	89	2,185,000	2	12,000	1	69,000
1996	6,790	77	9	1,183,000	7	8,000	3	22,000
1997	55,865	96	74	1,959,000	3	12,000	1	69,000

*assumes flows exceeding 5,500 cfs bypass power house, ascending hydrograph limb is 2,000 cfs/day, and receding hydrograph limb is 1,000 cfs/day.
Also assumes that canals are not in operation at the time of release, so that streamflows equal New Don Pedro Dam release.

- If possible, extend the duration of flows in the 5,500 cfs range for several days after the peak flow event to transport fine sediment downstream and deposit onto contemporary floodplains (designed to inundate at 4,000 cfs to 5,000 cfs).
- Larger releases (e.g., 12,000 cfs) should be of progressively shorter duration due minimize coarse sediment transport capacity and attenuate high flow peak magnitudes in downstream urban areas. Initial suggestions for high flow duration for 8,000 cfs, 10,000 cfs, and 12,000 cfs fluvial geomorphic releases are 3-day, 2-day, and 1-day duration respectively to minimize downstream gravel flux while exceeding bed mobility thresholds (Figures 3-22 to 3-29).
- Down-ramping rates should be at, or lower than, rates specified in the FSA and ACOE flood control manual to minimize juvenile chinook salmon stranding.
- Years in which flood management releases are necessary tend to come in multi-year sequences; therefore, in the first wet year after several sequential dryer years, a larger flow should be released if feasible (e.g., 12,000 cfs) to reverse riparian seedling initiation on active channel alluvial deposits, reducing riparian encroachment risk.
- The magnitude and duration of these flows should be re-evaluated continuously as part of the adaptive management program to evaluate whether bed mobility, bedload transport, sand transport, channel migration, and bed scour objectives are being met.
- Extremely wet years with extensive flood control releases in the spring should target very gradual ramping rates to encourage riparian regeneration on contemporary floodplains. Ramping rates targeting natural Fremont cottonwood regeneration should be less than 3 cm/day to allow their taproots to follow the descending moist capillary fringe.

These recommendations were developed to avoid interference with water allocations contained in the FERC Settlement Agreement, and to minimize loss of power generation revenues when bypass flows would normally occur. We suggest that geomorphic and biological monitoring experiments be developed and implemented (e.g., impacts of flow magnitude and duration to redd scour and egg mortality) prior to each winter season, in the event flood management releases occur. We recommend that the TRTAC closely monitor whether flood flows are achieving fluvial geomorphic and biological restoration objectives. The most significant potential shortcoming of the above approach is long sequences of dryer years (1971-1977, 1987-1994) that allow riparian vegetation to initiate and establish on newly rehabilitated reaches and newly deposited alluvial surfaces.

3.2.3. Constraints (sediment supply, floodway width, structural encroachment)

One result of the January 3, 1997 flood peak was the immediate perception that we needed to do something to prevent this from happening again. Some commonly suggested immediate solutions have been more storage (more or bigger dams), levees, or purchasing more flood control space in existing reservoirs. Out of this reactionary noise emerged a solution that could benefit a variety of needs: increased floodway capacity to improve flood management and flood control flexibility. There are several primary considerations when considering flood management solutions: maintain agricultural and municipal water supplies, providing flood control, protecting private and public property, ensuring human safety, positive and negative impacts to the environment, and cost. Purchasing flood control space in NDPP provides additional flood control protection, but reduces water supply, imposes a large cost to the public, and reduces environmental benefits provided by higher flood control releases. Constructing levees can contain floods, but they often provide a false-protection by allowing development behind them, and when they fail, flood damage increases. Additionally, the cost of levee construction and maintenance is large and greatly reduces the environmental quality of the river corridor.

A logical, long-term solution is to restore a continuous floodway and meander corridor from La Grange downstream to the San Joaquin River that provides flood conveyance up to 15,000 cfs upstream of Dry Creek and 20,000 cfs to the San Joaquin River. This strategy is integral to restoring fluvial geomorphic processes to the Tuolumne River, while at the same time reducing the risk of catastrophic floods (e.g., 1997 flood), greatly improves salmon habitat, provides property and human protection, preserves agricultural and municipal water supplies, and provides operators

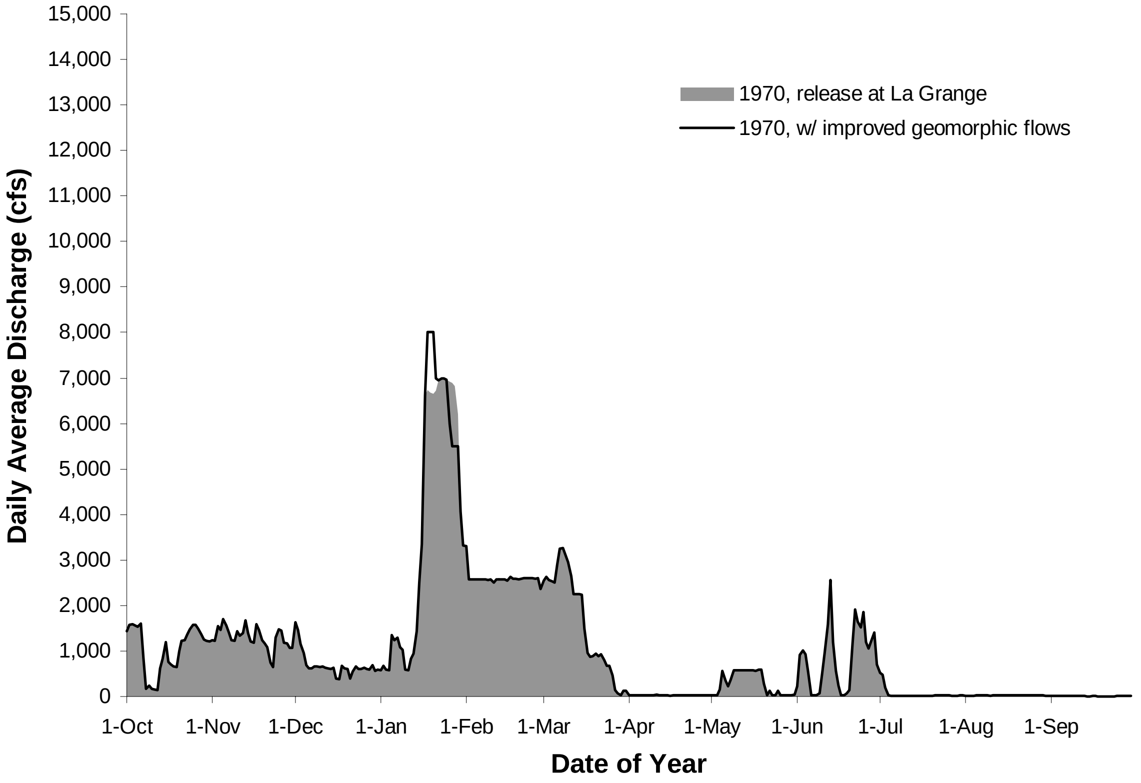


Figure 3-22. Tuolumne River annual hydrograph for 1970 with hypothetical flood control release hydrograph modifications to improve geomorphic processes.

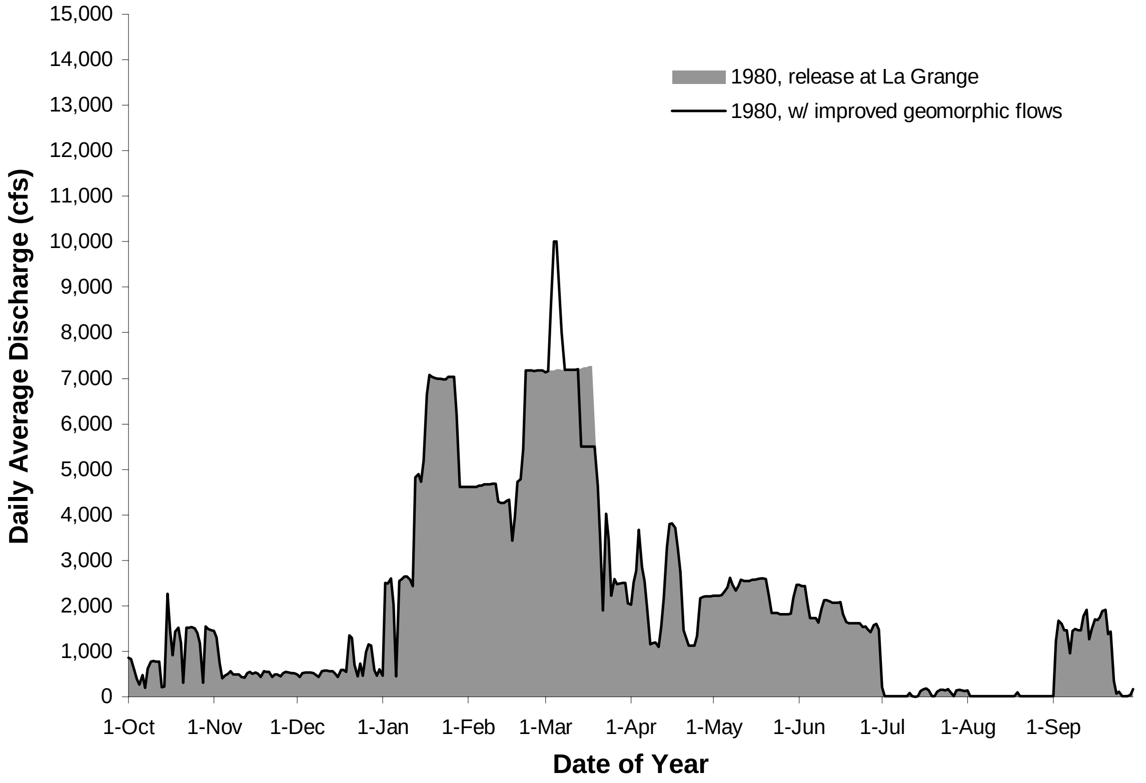


Figure 3-23. Tuolumne River annual hydrograph for 1980 with hypothetical flood control release hydrograph modifications to improve geomorphic processes.

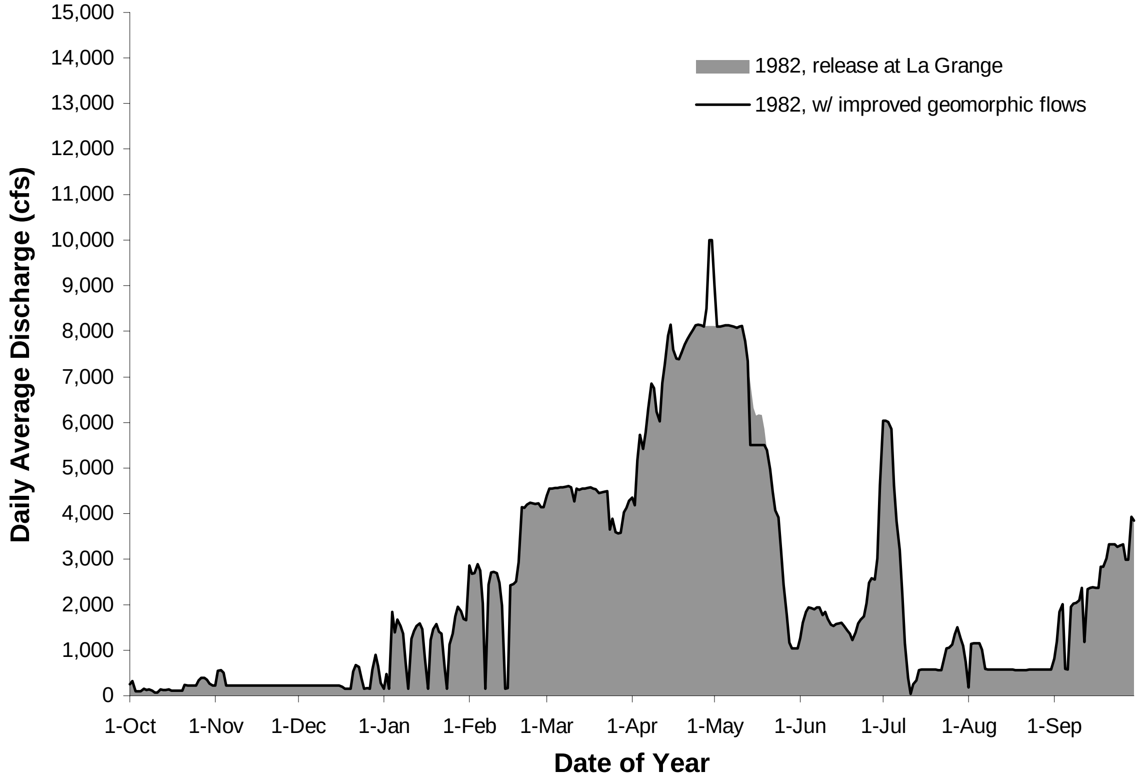


Figure 3-24. Tuolumne River annual hydrograph for 1982 with hypothetical flood control release hydrograph modifications to improve geomorphic processes.

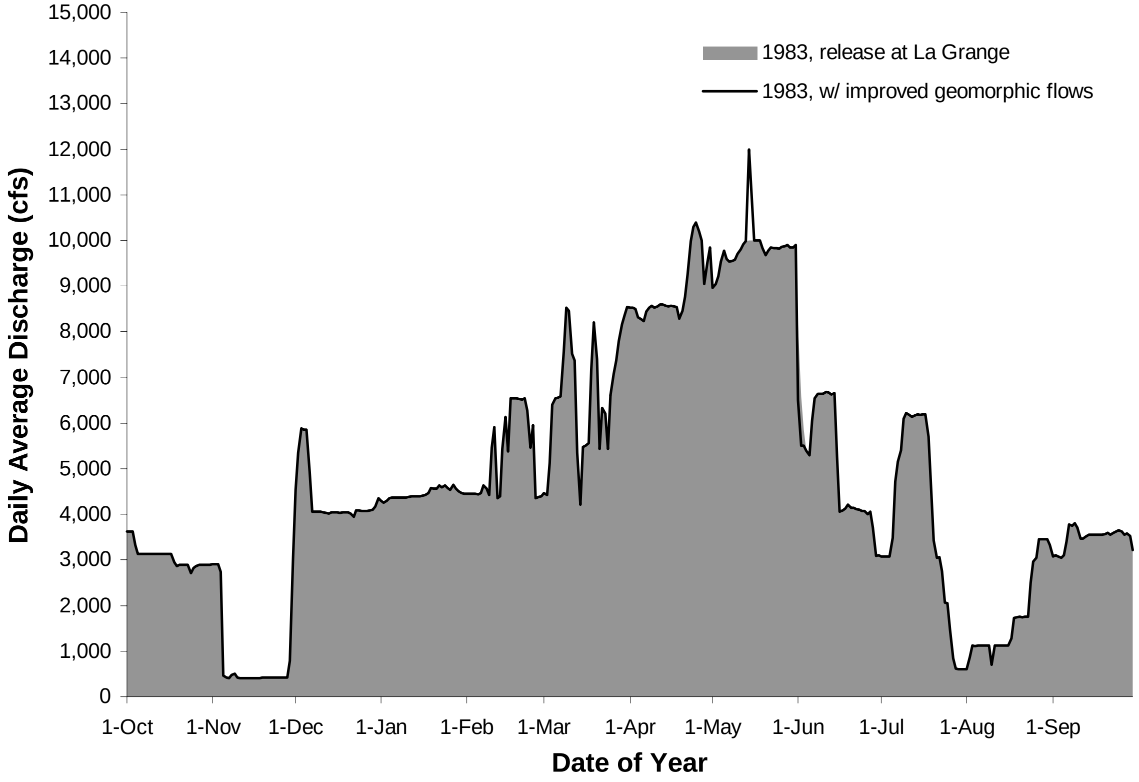


Figure 3-25. Tuolumne River annual hydrograph for 1983 with hypothetical flood control release hydrograph modifications to improve geomorphic processes.

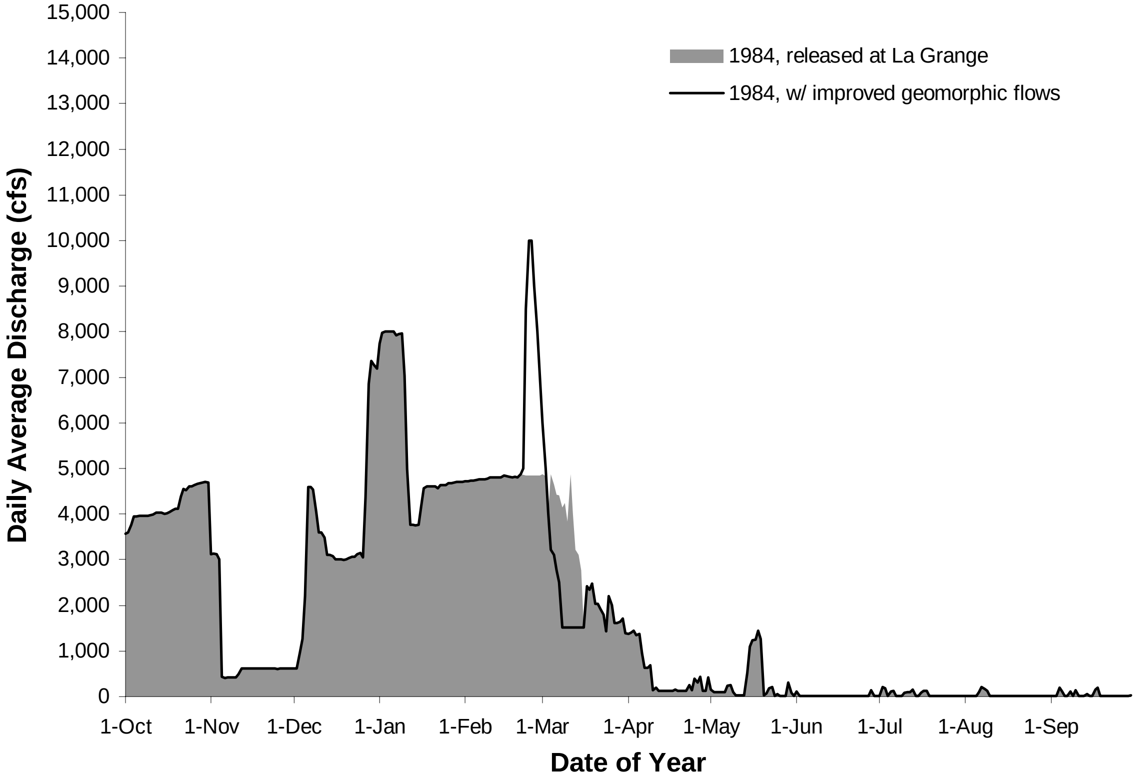


Figure 3-26. Tuolumne River annual hydrograph for 1984 with hypothetical flood control release hydrograph modifications to improve geomorphic processes.

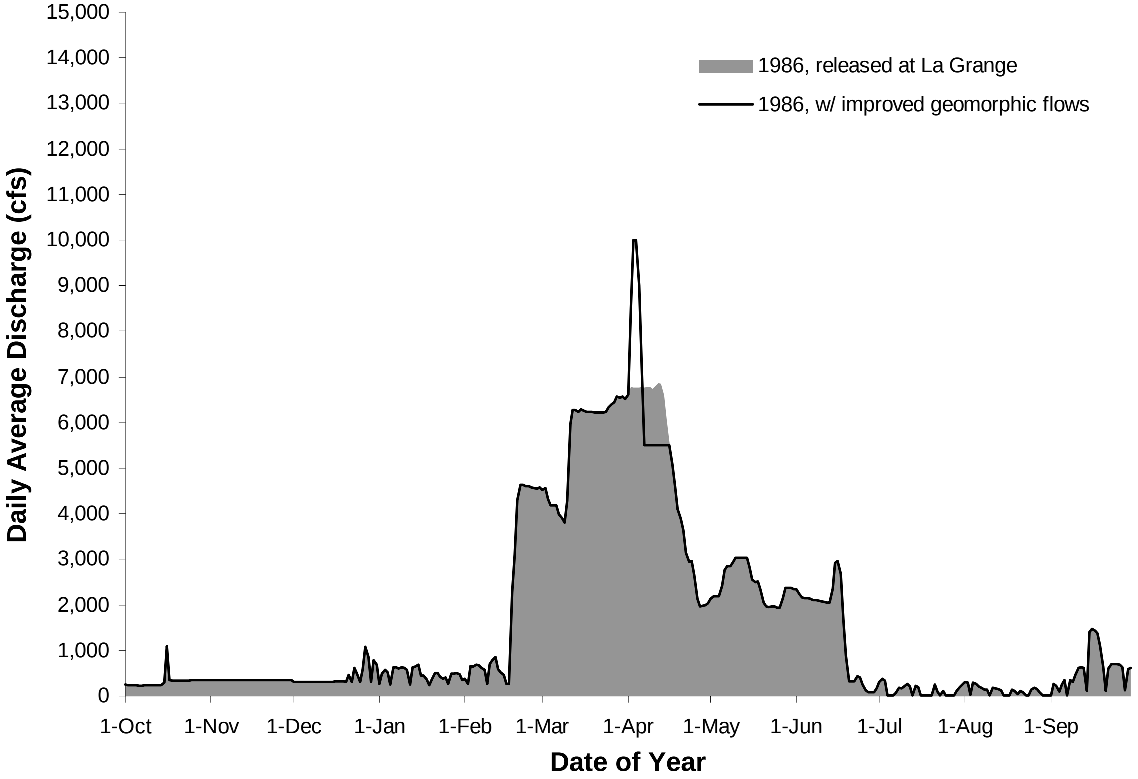


Figure 3-27. Tuolumne River annual hydrograph for 1986 with hypothetical flood control release hydrograph modifications to improve geomorphic processes.

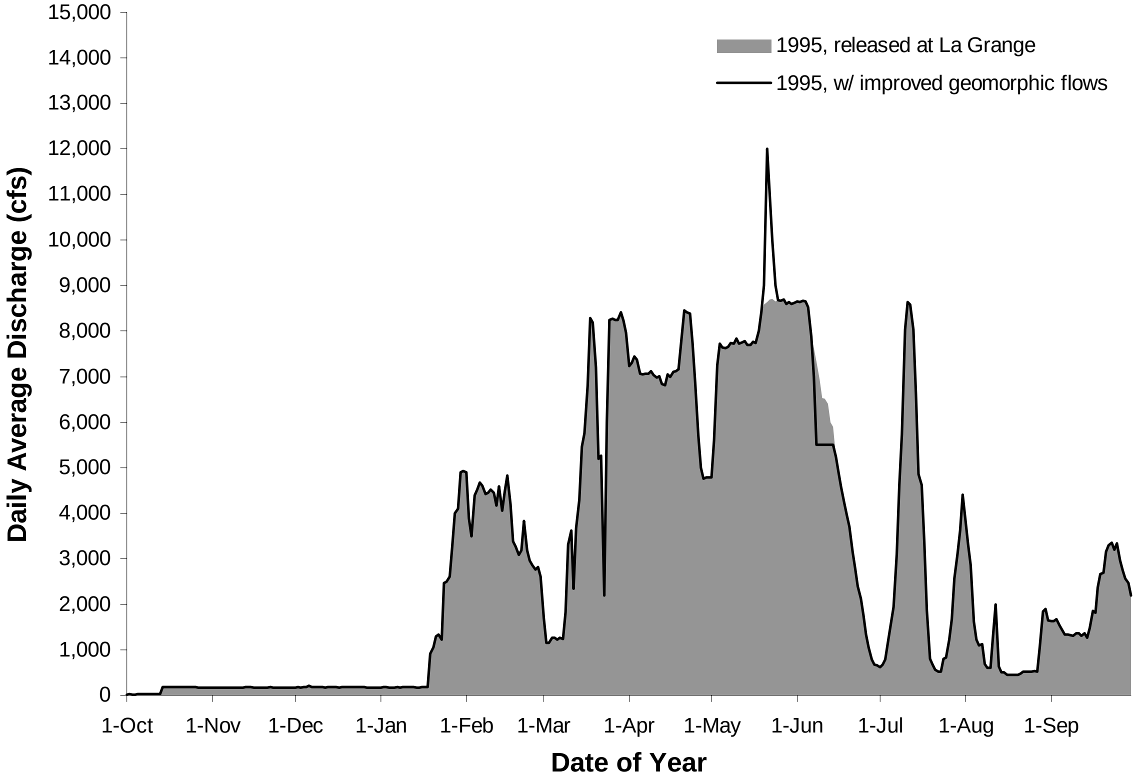


Figure 3-28. Tuolumne River annual hydrograph for 1995 with hypothetical flood control release hydrograph modifications to improve geomorphic processes.

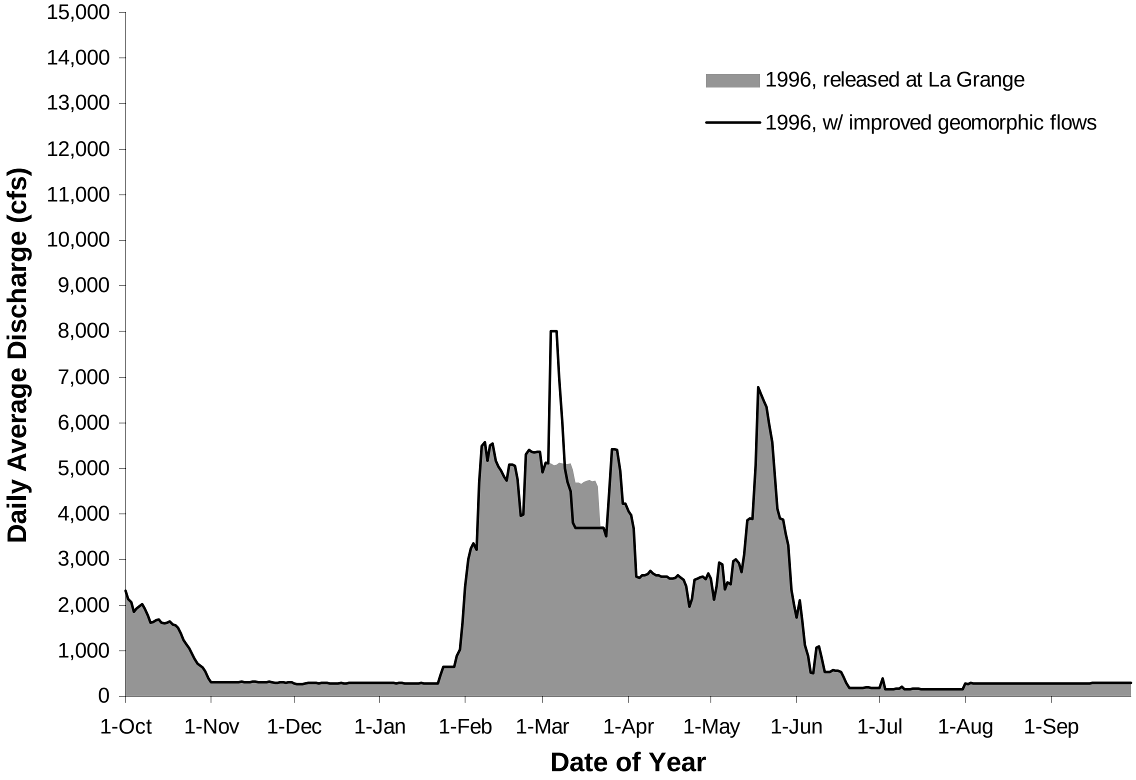


Figure 3-29. Tuolumne River annual hydrograph for 1996 with hypothetical flood control release hydrograph modifications to improve geomorphic processes.

greater flexibility during flood management releases. Increasing the magnitude and variability of high flows will allow greater frequency of exceeding thresholds for achieving Attributes (e.g., bed mobility, floodplain formation), while reducing the risk of catastrophic floods.

Constraints to increasing floodway capacity from 9,000 cfs to at least 15,000 cfs are: 1) thin topsoil dikes that confine the floodway through the Gravel Mining Reach (RM 34 to 40) are presently inadequate, and 2) the Modesto sewage treatment plant would require additional protection. The Gravel Mining Reach Restoration Project is being implemented to remove Constraint 1). The City of Modesto sewage treatment plant is presently being upgraded to withstand floods up to 20,000 cfs, and when completed, will remove Constraint 2). In the Gravel Mining Reach, greater floodway width will reduce future flood damage to active gravel mining operations.

In the aftermath of the 1997 flood event, many landowners in the lower river sought floodway or riparian easements to provide financial relief for repeated flooding of their agricultural lands. This easement program has recently added the 140 acre Grayson River Ranch Project (RM 5-6). The Wetlands Reserve Program (administered by the USDA Natural Resources Conservation Service in cooperation with the East Stanislaus Resource Conservation District) and the Anadromous Fish Restoration Program (USFWS) have funded and administered the conservation easement agreement and riparian restoration program to date. Several other additional applications to this program are pending easement funding.

Other potential constraints include gravel loss immediately downstream of La Grange Dam (which will require artificial introduction to compensate), power generation losses during flows exceeding the 5,400 cfs turbine capacity, and flood routing management in the entire San Joaquin River floodway. However, the recommended short duration, large magnitude peak flows will minimize impacts to these constraints. These flows will transport and scour alluvial deposits, but the short duration will minimize net transport, thus minimizing gravel/cobble introduction needs. The short duration peak will also reduce power generation losses and minimize flood routing problems in the lower San Joaquin River. Because these flows exceed bed mobility thresholds, and may exceed bed scour and channel migration thresholds, they are fundamental components of this Restoration Plan. In summary, increasing high flow release magnitude, combined with the improved floodway width, should benefit salmon production as well as improving flood management on the Tuolumne River. These benefits can be extended to the San Joaquin River, if improvements to floodway width and similar actions occur there as well.

3.3. AGGREGATE SOURCE INVENTORY

The aggregate source inventory summarizes the location and rough volumes of aggregate potentially available for restoration projects. By documenting the volume and location of sources, overlaying property ownership, and computing haul distances from source to restoration site, we evaluated the most cost-effective aggregate sources available. The inventory is based on our own field reconnaissance and investigations by the California State Department of Conservation, Division of Mines and Geology, in Special Report 173 (Higgins and Dupras 1993). The geographic scope of Special Report 173 was specifically confined to Stanislaus County. The Tuolumne River has a limited supply of aggregate compared to the Merced River because the river bottomland width is much narrower. Therefore, we revisited potential aggregate sources on the Tuolumne River as well as those on the Merced River.

Aggregate sources on these two rivers typically occur in dredger tailings and "pit run" aggregate excavated from historic terraces across the river corridor. Dredger tailings have had most of the gold removed and are commercially less valuable because organic material is often mixed with the aggregate. Pit run aggregate is much more commercially valuable because it typically has minor amounts of woody debris mixed in. Dredger tailings are therefore preferable restoration materials because they are in less demand by the aggregate industry, and their use results in less conflict with preferred aggregate sources.

3.3.1. Special Report 173

Aggregate mineral resources in the County are classified as (Higgins and Dupras, 1993):

- Aggregate Resources, which include reserves as well as all potentially useable aggregate materials that may be mined in the future, but for which no mining permit has been granted, or for which marketability has not been established.
- Aggregate Reserves, which are aggregate resources determined to be acceptable for commercial use, that exist within properties owned or leased by aggregate producing companies, and for which permits have been granted to allow mining and processing.

Special Report 173 identifies 540 million tons of aggregate resources available in the Stanislaus County, of which 217 million tons are located within the Tuolumne River Geographic Area (Figure 3-30). Presently, permitted reserves total 27.7 million tons for Stanislaus County, which will continue to increase over time as urban expansion and aggregate demand grows. The report identifies nearly the entire Tuolumne River valley as an aggregate resource, and delineates polygons within the valley (with estimated aggregate depths) to estimate aggregate volumes; however, the polygon areas are too large to be of use in quantifying local gravel sources. All estimated volumes assume that the aggregate is extracted to the maximum depth possible (bedrock), which ranges from five to thirty-five feet. This will result in additional pits adjacent to the Tuolumne River, and increased confinement of the bankfull channel. We re-evaluated aggregate sources based on smaller, more site-specific polygons, and in most reaches estimated aggregate volumes based on excavating down to a contemporary floodplain elevation rather than to bedrock.

3.3.2. McBain & Trush inventory

Our reconnaissance level survey focused on dredger tailings on the Merced River corridor, remaining dredger tailings in the Tuolumne River corridor, and remnant materials left after dredger tailings were removed for construction of NDPP. The Merced River corridor near Snelling is nearly 1.5 miles wide, three times wider than the Tuolumne River corridor (0.5 miles wide). The entire corridor width was dredged for gold in both rivers, and the larger corridor width on the Merced River resulted in considerably more tailings. Additionally, slow growth in Merced County has reduced local aggregate demand, so most of the tailings remain. In contrast, rapid growth in Stanislaus County has created a large demand for local sources of aggregate, and Tuolumne River aggregate resources have been rapidly dwindling. Demand on Merced River sources will certainly rise as the new University of California campus is constructed in Merced.

A potentially competing use for aggregate resources will be river restoration; however, there are some differences in aggregate quality needs between commercial and restoration uses. Because the channel restoration projects needing large volumes of aggregate are largely pit filling projects, woody material in the dredger tailings is irrelevant. Therefore, restoration efforts should target dredger tailings as the primary source of construction aggregates, which could minimize future conflict or competition with commercial aggregate operators on the river.

Because SMARA and Special Report 173 consider dredger tailings to be part of the County aggregate resources, the use of dredger tailings for restoration projects would involve the entire County-use permit process, including CEQA and development of reclamation plans. Development of County use permits is time-intensive, and restoration could leave considerable volumes of aggregate left in place at restoration sites as mining pits are restored and instream gravel storage is increased.

We located potential aggregate sources on the Tuolumne River and Merced River by searching in the field. We classified a source as viable if it satisfied the following criteria:

- It was lower commercial quality than pit-run aggregate, so we would not be removing a high quality aggregate reserve from commercial/ infrastructure use.
- It could be extracted without creating a pit that could be connected to the river in the near future to avoid perpetuating additional gravel mining pits adjacent to the river.
- It could be extracted and the extraction site restored to better conditions (creating shallow off-channel wetlands, or restoring a functional floodplain connected to the river, or replacing a xeric surface with native woody riparian vegetation).
- It was within 20 miles one-way from most of the channel restoration projects planned for the Tuolumne River.

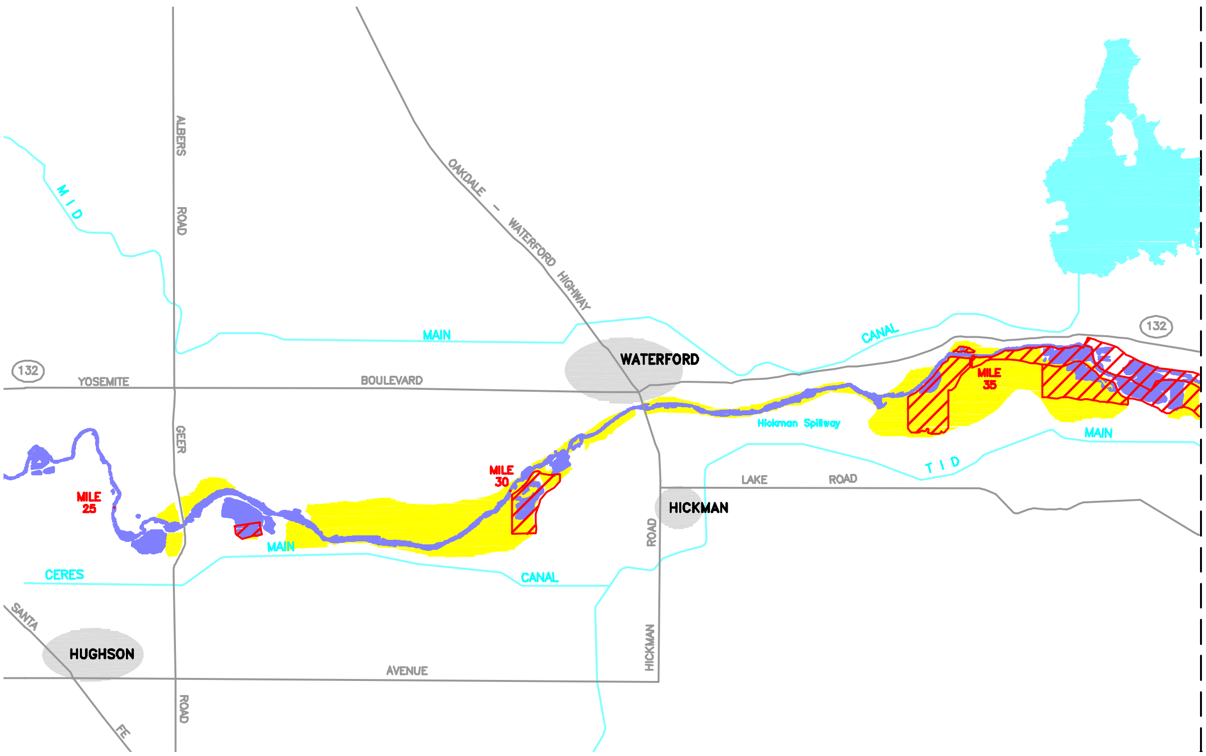
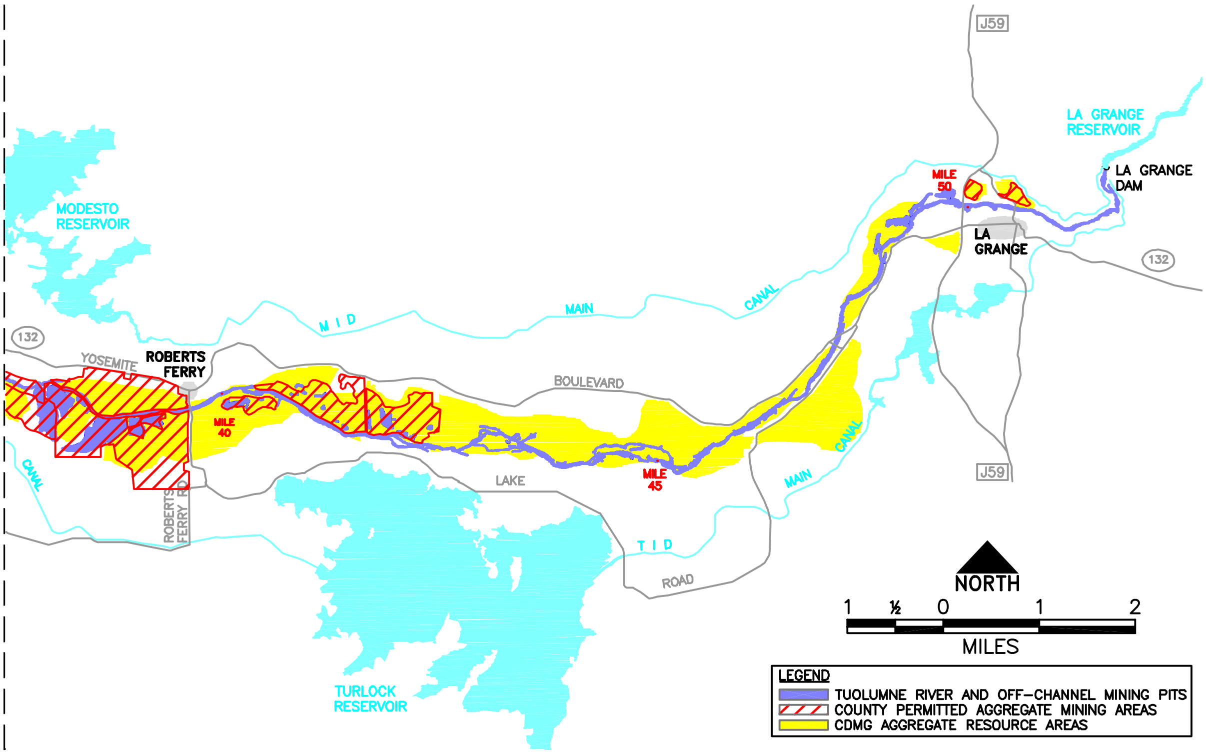


Figure 3-30. California Division of Mines and Geology (CDMG) Aggregate Resource Areas (Higgins and Dupras 1993) and currently permitted aggregate mining areas identified on the Tuolumne River between Santa Fe Bridge (RM 21.7) and La Grange Dam (RM 52).

Sites were given a higher priority if they were on public land, within the boundary of permitted aggregate extraction operation on dredger tailings, or on private land whose owners expressed an interested in having aggregate removed from their property. Priority was also give to sites with large volumes within a single parcel, making permitting and other implementation considerations easier. Lower priority was given to sites on private land where the landowner had either not been contacted, or had not expressed an interest in removing material. Our search boundary on the Tuolumne River was from La Grange Dam (RM 52.0) to Roberts Ferry (RM 40); on the Merced River, it focused strictly on dredger tailings from Merced Falls (RM 55) to below Snelling (RM 45).

Volumes for each site were estimated using simple methods to provide reasonable accuracy with low cost. We delineated the surficial extent of each particular deposit on orthorectified aerial photographs or topographic maps, then estimated the depth of excavation for each boundary. Depths were estimated by measuring the elevation difference between the top of the deposit and a reclamation surface elevation. The area of the deposit multiplied by the depth of excavation provided a volume estimate. There were a few sites where aggregate operators provided volume estimates, another site where topographical surveys provided volume estimates, and a few sites where depths were not measured and no volumes were estimated. The locations and volume estimates were digitized as a GIS layer to overlay on assessors maps and to be able to estimate travel distance to future restoration project sites.

Results of our Tuolumne River surveys and Merced River surveys are shown on the Figures 3-31 and 3-32, respectively, and in Table 3-9. Eight sites stand out among all the others: 1) Materials deposited into La Grange Reservoir during the 1997 flood, 2) Reeves spawning gravels near La Grange (RM 50.5), 3) La Grange Reservoir delta, 4) Crooker dredger tailings (leased by Santa Fe Aggregates at RM 41), 5) Cree dredger tailings (leased by Western Stone at RM 42), 6) Hall dredger tailings at RM 43, 7) Zanker dredger tailings at RM 46, and 8) the Merced River Ranch (318 acres of Merced River dredger tailings) currently being purchased by CDFG. The Reeves spawning gravels are one of



the most important gravel resources left on the Tuolumne River. The Reeves property is located on the north side of the Tuolumne River, and is an active sand mining pit. A unique aspect of this sand deposit is that it is interspersed with thin lenses of small to medium gravels. As the sand has been mined, the gravels were screened and stockpiled as waste material. There may be up to 75,000 yd^3 of these gravels surrounding the sand pit. The range of gravel sizes contained in these piles is consistent with the range of gravel sizes preferred by salmon for spawning habitat. Because these gravels are stockpiles only several hundred feet from the primary spawning area, introducing this gravel would be extremely economical. Introducing large quantities of this material back into the river is perhaps the highest restoration priority for the Tuolumne River (see Sediment Management and Implementation Plan description in Section 4.5.6)

The La Grange Reservoir delta was formed during the 1997 flood, when 45,000 cfs was spilled down Twin Gulch, incising a 25 ft to 50 ft gorge into the bedrock and depositing this material into La Grange Reservoir. Topographical surveys estimate near 500,000 yd^3 of fractured rock and sand available for removal at no purchase cost. This material should only be used to fill pits because it is too angular for use as riverbed material; using this material instead of aggregate would reduce real and perceived loss of future aggregate sources for societal use. The primary drawback to using this material is the cost associated with constructing a road into the canyon, trucking material out of the canyon, and transporting it to downstream restoration sites.

The Crooker Site is much closer to restoration sites, and contains large volumes of dredger tailings that are permitted for extraction. Close proximity makes it an less expensive source. Santa Fe Aggregates estimates approximately 4,000,000 to 8,000,000 tons (2,600,000 to 5,200,000 yd^3) of material available if excavated below groundwater in a manner similar to downstream pits. Creating new pits at this site, however, would create the same problem the material is being used to fix: in-channel and off-channel pits. Excavating down to a contemporary floodplain elevation would reduce the available volume to roughly one-half to one-third the estimated volume presented above. Because these tailings are leased by a commercial aggregate

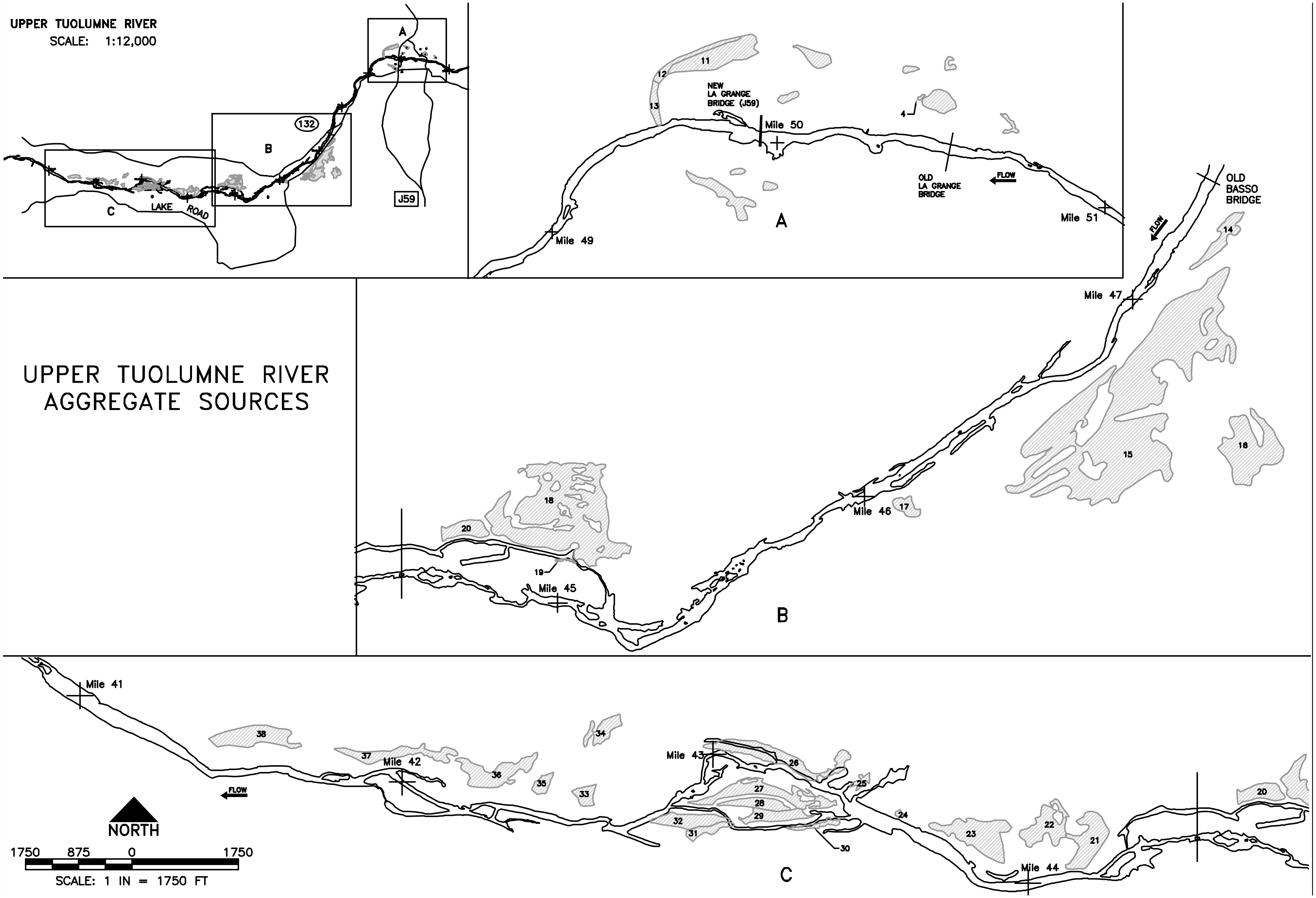


figure 3-31 Gravel inventory sites identified on the Tuolumne River between Roberts Ferry (RM 40) and La Grange Dam (RM 52)

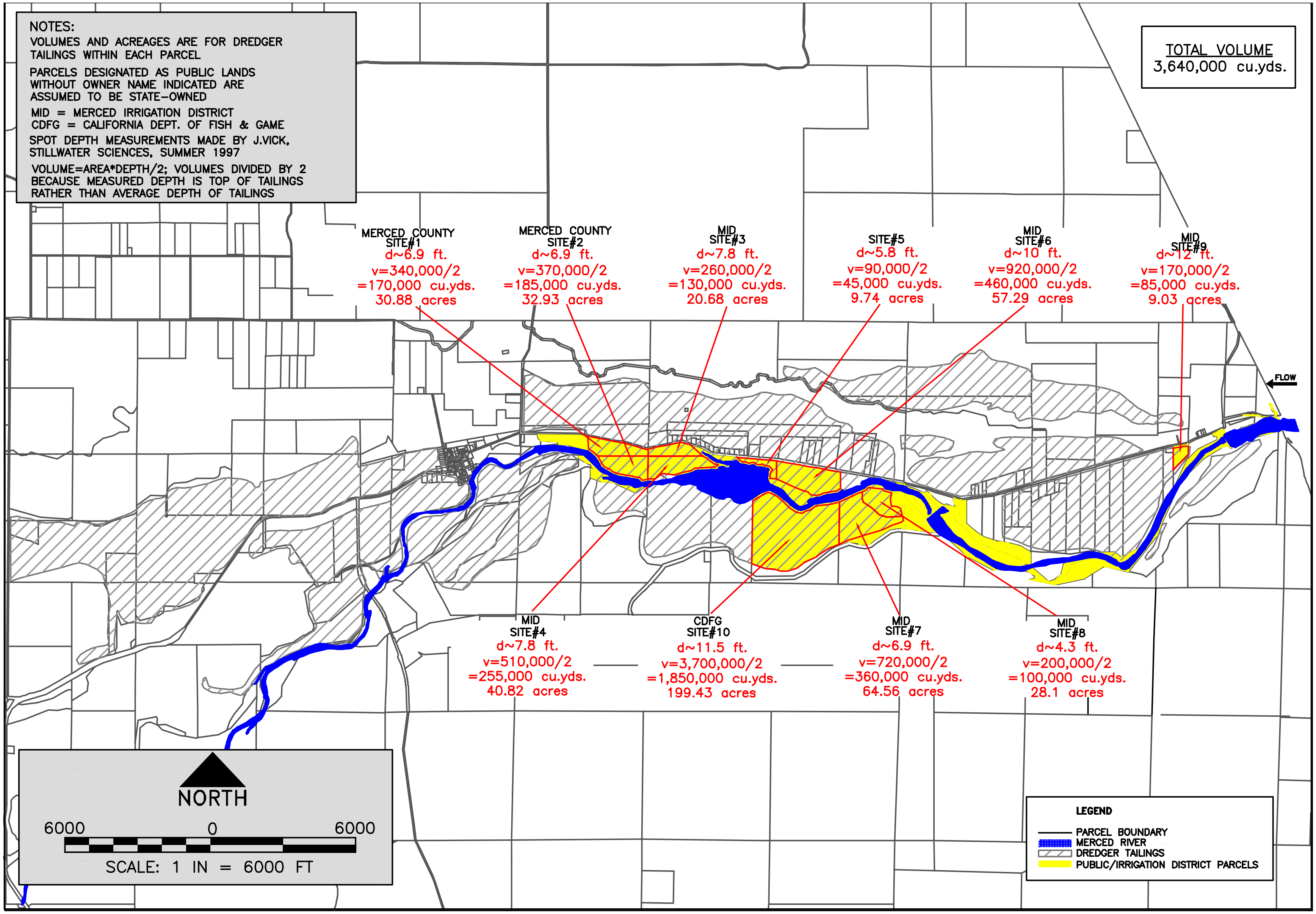


*Figure 3-32 Gravel inventory sites identified in the Merced River dredger tailings, near Snelling CA. Volumes estimated by Area*Depth/2 to provide more conservative volume estimate in these variable height dredger tailings.*

Table 3-9. Summary of upper Tuolumne and Merced River aggregate source inventory.

TOULUMNE RIVER AGGREGATE SOURCES

Site #	Approximate Average Depth (ft.)	Surface Area of Source (sq ft)	Surface Area of Source (ac)	Approximate Volume of Source (cu. yd.)
1	25	25,000	0.57	12,000 *
2	Volume from DTM	20,000	0.46	2,000
3	30	102,000	2.34	57,000 *
4	27	5,000	0.11	3,000 *
5	Volume from DTM	18,000	0.41	2,000
6	10	87,000	2.00	32,000
7	8	30,000	0.69	9,000
8	2	22,000	0.51	2,000
9	10	175,000	4.02	65,000
10	12	16,000	0.37	7,000
11	12	349,000	8.01	155,000
12	20	101,000	2.32	75,000
13	12	68,000	1.56	30,000
14	5	159,000	3.65	29,000
15	4	3,811,000	87.49	565,000
16	2	592,000	13.59	44,000
17	8	77,000	1.77	23,000
18	3	1,647,000	37.81	183,000
19	5	7,000	0.16	1,000
20	3	143,000	3.28	16,000
21	2	294,000	6.75	22,000
22	1.5	252,000	5.79	14,000
23	3	391,000	8.98	43,000
24	3	11,000	0.25	1,000
25	7	31,000	0.71	8,000
26	2	375,000	8.61	28,000
27	10	321,000	7.37	59,000 *
28	15	126,000	2.89	35,000 *
29	1	145,000	3.33	5,000
30	15	46,000	1.06	26,000
31	16	78,000	1.79	46,000
32	3	182,000	4.18	20,000
33	2.5	74,000	1.70	7,000
34	1	122,000	2.80	5,000
35	2.5	60,000	1.38	6,000
36	10	282,000	6.47	104,000
37	10	227,000	5.21	84,000
38	10	295,000	6.77	109,000
			TOTAL:	**1,861,000**

MERCED RIVER AGGREGATE SOURCES

Site #	Approximate Average Depth (ft.)	Surface Area of Source (sq. ft.)	Surface Area of Source (ac)	Approximate Volume of Source (cu. yd.)
1	6.9	1,345,000	30.88	172,000 *
2	6.9	1,434,000	32.92	183,000 *
3	7.8	901,000	20.68	130,000 *
4	7.8	1,778,000	40.82	257,000 *
5	5.8	424,000	9.73	46,000 *
6	10	2,496,000	57.30	462,000 *
7	6.9	2,812,000	64.55	359,000 *
8	4.3	1,224,000	28.10	97,000 *
9	12	393,000	9.02	87,000 *
10	11.5	8,687,000	199.43	1,850,000 *
			TOTAL:	**3,644,000**

* These sources are undisturbed dredger tailings or gravel cones with "sawtooth" morphology. Volumes estimated by Area*Depth/2 to provide more conservative volume estimate in these variable height dredger tailings.

company, any negotiated change to the approved reclamation plan would need to consider compensating forgone mineral rights

The Cree dredger tailings (RM 42) are also closer to restoration sites, but do not contain nearly the volume of dredger tailings as the Crooker site and Hall site. Most tailings were removed during NDPP construction, and remaining tailings are currently permitted for extraction and leased by a commercial aggregate company. The Cree dredger tailings (sites 33-38 on Figure 3-31) may yield over 300,000 yd^3 of aggregate. The site could yield more aggregate volume if off-channel wetlands are created on the far north side of the floodway (away from the bankfull channel). Very little volume remains in sources closer to the river, and should not be excavated below a contemporary floodplain elevation (approximately 4-5 ft above the low water surface) to avoid additional pit capturing and salmon stranding problems.

The Hall dredger tailings (RM 43-44) have not been permitted or disturbed, and the landowner has expressed interest in using these dredger tailings for local restoration purposes (Sites 18-32 in Figure 3-31) (see Dredger Tailing Reach restoration project in Section 4.3.8). Up to 500,000 yd^3 are available if dredger tailings are lowered to contemporary floodplain elevation (approximately 4-5 ft above low water surface). We recommend these materials be used locally to implement the Dredger Tailing Reach restoration project because no on-highway hauling would be needed and the available material should be sufficient to restore SRP 2, SRP 3, recreate bankfull confinement, and add much needed gravel supply to the Tuolumne River.

The Zanker dredger tailings (RM 46) were largely removed during NDPP construction; however, some areas still contain considerable quantities of aggregate. The landowner has expressed interested in using these remnant tailings for stream restoration. The site is on the south side of Lake Road (Sites 15 and 16 in Figure 3-31), isolated from the Tuolumne River floodway. There is considerable topographic diversity on the site, with cottonwoods established in lower elevation sections (closer to the summer groundwater table), and annual grasses and exposed cobbles over the remainder. There is tremendous opportunity to improve site conditions and increase wetland habitat with riparian vegetation. There may be over 600,000 yd^3 of material in this reach. The proximity of the aggregate source to potential spawning gravel introduction sites, coupled with potential landowner interest in restoring the site, makes it a high priority aggregate source site.

Finally, the Merced River Ranch, if CDFG completes their land purchase, could provide nearly 2,000,000 yd^3 of aggregate for future restoration purposes (Figure 3-32). The primary limitation for Tuolumne River use is haul distance: 32 miles round trip to La Grange, 58 miles round trip to Waterford, and 66 miles round trip to Geer Road Bridge over the Tuolumne River.

The sites with single landowner and large aggregate volume should be used for larger restoration projects. Numerous smaller sources identified in Figure 3-31 and 3-32 should be used for smaller restoration projects, or when large local restoration projects could use them to reduce transportation and purchase costs. However, if these smaller sites are not permitted and SMARA compliant, the effort expended to permit these smaller sites may cost more than if using already permitted commercial sources. Therefore, each restoration project will need to evaluate source material on a case-by-case basis to determine the most cost-effective way of securing restoration materials.

3.3.3. Summary

There is a finite volume of aggregate within the Tuolumne River; Higgins and Dupras (1993) estimatd that the volume of currently permitted reserves would be depleted by 2002 based on forecasted population growth for the region. The limited supply of commercial grade aggregate on the Tuolumne River will increase the competition for these resources among aggregate operators as well as restoration practitioners. To avoid this conflict, we may be forced to use Merced River dredger tailings in restoration activities, which may significantly increase the cost and environmental impacts of future projects. To implement future restoration projects, the TRTAC must:

1. Increase dialog with the aggregate extraction operators to minimize future competition and conflict.
2. Secure important dredger tailing deposits for future restoration projects, particularly those closest to the river channel.

3. Participate in future aggregate extraction permitting to ensure that permitting conditions address ecological, channel, and floodplain conditions along the Tuolumne River corridor. As in recently funded projects to restore damage caused by previous aggregate extraction, preservation of sites prior to resource development may be a less expensive alternative to restoration.

3.4. RIPARIAN CORRIDOR EVALUATIONS

Dramatic losses in riparian vegetation coverage, and the growing awareness that riparian vegetation is vital to river ecosystem integrity, have elevated the importance of riparian vegetation preservation and restoration. While benefits of riparian vegetation to the river ecosystem and salmon habitat have been well documented (Junk et al. 1989; Stanford et al. 1996), interactions between riparian vegetation and fluvial processes have not.

Our riparian evaluation had three components: 1) a detailed inventory of riparian vegetation along the lower 52 miles of the Tuolumne River, 2) a description of current riparian vegetation by geomorphic zone and reach, 3) an evaluation of fluvial and hydrologic interrelationships with riparian vegetation in three channel morphologies, and 4) a discussion of factors limiting natural regeneration. Improved riparian revegetation plans and channel/floodplain restoration designs will profit from these study components and will help identify and prioritize potential riparian restoration projects (see Chapter 4).

3.4.1. Tuolumne River Riparian Inventory

The first step in our riparian inventory of the lower 52 miles of the Tuolumne River corridor was to choose a classification scheme for defining riparian vegetation units. We chose to use the plant series classification, developed by Sawyer and Keeler-Wolf (1995) because it incorporates both canopy dominance and subdominant understory in the classification. The second step was to map and inventory riparian vegetation boundaries based on these plant series found in the Tuolumne River corridor.

3.4.1.1. Riparian Series List

A plant series is a vegetation sub-unit or stand dominated by a single plant species, or shared among a few co-dominant species. Usually several plants are associated with a series, though in some cases a series can be only one species (e.g., Giant Reed Series). Sawyer and Keeler-Wolf (1995) define hundreds of plant series, 22 of which were documented in the lower Tuolumne River corridor (Appendix B). During the riparian inventory, we documented four new plant series: box elder, Oregon ash, tree of heaven, and edible fig. Box elder and Oregon ash are native to the Tuolumne River; tree of heaven and edible fig are exotic. Exotic plants are numerous, and comprise five of the 29 observed series: eucalyptus, edible fig, giant reed, lamb's quarters, and tree of heaven.

While most riparian vegetation fit into the Sawyer and Keeler-Wolf classification, some riparian vegetation could not be classified as a series. These deviations were typically a single plant (e.g., an isolated valley oak), or a small clump of identical individuals (e.g., weeping willow, Himalayan berry). These were mapped as individual plants, and labeled on the inventory maps by including their scientific names in the map legend (Appendix B)[5].

Of the 29 series identified, several have been greatly reduced over time, making their perpetual existence threatened, or very threatened. These series often provide habitat for rare, threatened or endangered animal species. The Nature Conservancy characterized the relative abundance of California's general vegetation types (initially created by Holland (1986)) using the California Department of Fish and Game's Natural Diversity Database (NDDB) program. A series type is identified as "threatened" if there is only 2,000 to 10,000 acres of the remaining vegetation type left in California.

We included The Nature Conservancy classification and the NDDB classification to match series on the Tuolumne River with threatened vegetation types (Appendix B). All native terrestrial vegetation within the Tuolumne River riparian

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[5] A single riparian inventory map of the entire corridor is included in the back of the report. The complete set of 19 riparian inventory maps is included on the enclosed CD-ROM.

corridor, with the exception of narrow-leaf willow and white alder, are classified as very threatened or threatened (Appendix B).

3.4.1.2. Riparian Species List

A list of common plant species in the lower Tuolumne River corridor was prepared (Appendix B). Each species was characterized by: (1) native or exotic, (2) whether the plant is invasive when it colonizes a site (3) growth habits (tree, shrub, vine, etc.), (4) USFWS hydric codes (wetland obligate, facilitative wetland plant, etc.), and (5) SCS codes. Of the 106 species comprising riparian vegetation inventoried, 64 were native and 42 were exotic. Of the 42 exotic species observed, 26 were invasive and actively displacing native species.

Native riparian plant species are adapted to flooding, channel migration, channel avulsion, and sediment deposition and scour that occurred before human alteration. Exotic plants have out-competed many native riparian plant species since flow regulation began because exotic plants are better adapted to the altered, post-NDPP riparian corridor. Exotic plants are effective inter-specific competitors, often growing in pure stands that exclude all other plant species. Many exotic plant species cover so much area within the riparian corridor they were mapped as plant series. Four exotic plant species represent 67% of all mapped exotic plants in the Tuolumne River riparian corridor (Appendix B). Eucalyptus, edible fig, giant reed, and tree of heaven form large stands that interfere with native hardwood recruitment and regeneration. Stands of exotic species are so extensive and aggressive they greatly impair potential riparian corridor recovery and should be targeted for removal in all future restoration projects.

Eucalyptus provides a good example of how exotic plants can alter an environment at the expense of native species. Eucalyptus is planted for wind breaks and green strips due to its fast growth rate; however, its reproductive propensity has allowed it to escape from urban plantings and invade the riparian corridor. Eucalyptus has the largest exotic species coverage in the riparian corridor (Table 10 and Appendix B), and is difficult to eliminate because of its popularity with landscapers, ranchers, and landowners. The problem with eucalyptus is its allelopathic effect: as eucalyptus leaves drop and accumulate they change the soil chemistry and prevent other plant species from growing. The chemicals in eucalyptus leaves sterilize the surrounding soil, an effect that persists for years.

Several willow species, Fremont cottonwoods, and valley oaks deserve further discussion because of their habitat value, dominance, or rarity. Willows along the Tuolumne River occur in either shrub form (e.g., narrow leaf willow), or tree form (e.g., Goodding's black willow). Since the NDPP was completed, the reduced high flow regime has favored narrow-leaf willow because they have the longest seed dispersal period which overlaps with stable summer base flows, and they are well adapted to survive infrequent high energy conditions. Narrow-leaf willow is a shrub type, grows in dense monotypic stands, and was the most abundant of all willow species mapped. Narrow-leaf willow is problematic in many reaches due to its ability to easily colonize riverbanks, create riparian berms, and reduce floodwater access to floodplains. The only other shrub willow common throughout the entire lower river was arroyo willow. It was often the dominant or co-dominant plant species within a series. Arroyo willow is far more common in the gravel-bedded zone than the sand-bedded zone.

Tree willow species are dominated by Gooding's black willow because it is best adapted to the artificially dryer microclimatic conditions caused by riparian vegetation clearing. It is the most abundant tree willow and is the dominant species in many stands. Pacific willow and red willow are far less abundant, and were documented only as sub-dominant plants in other vegetation series.

Fremont cottonwood is commonly observed within the lower Tuolumne River corridor, but nearly all stands and individuals are old and senescent. The only exception was in the Dredger Tailing Reach (Reach 6), where remnant dredger ponds have allowed cottonwoods to regenerate. The general absence of young cottonwood cohort is troublesome because senescent cottonwoods have already made most of their ecological contribution (detritus and seed production), and are no longer growing and producing large seed quantities. Without younger age classes, dying trees cannot be replaced, and additional significant losses to mature cottonwood stands are imminent. This attrition process has been observed on other regulated alluvial rivers, potentially leading to the collapse of a river's cottonwood stands (Merigliano, 1996). The best

Table 3-10. Total surface area of riparian vegetation series within the lower Tuolumne River corridor.

		Total Area (acres)	**Maximum Patch Size (acres)**	**Minimum Patch Size (acres)**	**Number of patches**
Native Riparian	Arroyo willow	4.1	1.02	0.11	9
	Black willow	230.6	15.67	0.01	210
	Blue elderberry	1.4	0.24	0.02	16
	Box elder	112.8	5.76	0.03	148
	Button bush	3.0	0.46	0.01	18
	California buckeye	10.1	6.47	0.05	6
	California grape (*Vitis californica*)*	0.7	0.33	0.14	3
	California walnut (*Juglans nigra*)*	13.8	12.02	0.03	8
	Dusky willow	4.2	1.22	0.02	17
	Fremont cottonwood	456.6	21.58	0.00	449
	Mixed willow	148.5	6.64	0.06	142
	Narrow-leaf willow	514.7	10.71	0.02	617
	Oregon ash	7.0	1.39	0.01	24
	Pacific willow	4.8	1.65	0.02	9
	Valley oak	620.5	44.53	0.02	439
	Western sycamore (*Platanus racemosa*)*	0.1	0.05	0.01	2
	White alder	30.6	3.12	0.01	88
	TOTAL	**2163.4**	**44.53**	**0.00**	**2205**
Native upland	Blue oak	33.9	12.90	0.03	21
	Bush lupine (*Lupinus sp.*)*	2.3	1.87	0.43	2
	Interior live oak	101.2	92.48	0.07	11
	TOTAL	**137.4**	**92.48**	**0.03**	**34**
Emergent	**TOTAL**	**40.9**	**6.27**	**0.02**	**72**
Exotic	Black locust (*Robinia psuedoacacia*)*	0.1	0.13	0.13	1
	Disturbed/miscellaneous exotics	6.3	3.72	0.28	5
	Edible fig	1.5	0.73	0.06	3
	English walnut (*Juglans regia*)*	1.9	1.46	0.08	5
	Eucalyptus	11.7	5.05	0.03	13
	Giant reed	5.2	0.65	0.01	47
	Himalayan berry (*Rubus discolor*)*	3.6	0.79	0.07	15
	Lamb's quarters	1.0	0.96	0.96	1
	Tamarisk (*Tamarix* sp.)*	0.2	0.14	0.02	2
	Tree of heaven	8.4	2.23	0.03	18
	Tree tobacco (*Nicotiana glauca*)*	2.7	0.66	0.15	8
	Weeping willow (*Salix babylonica*)*	0.7	0.25	0.22	3
	TOTAL	**43.1**	**5.05**	**0.01**	**121**
	TOTAL	**2384.9**	**92.48**	**0.00**	**2432**

* Not defined as a vegetation series because they are individual plants, groups of individuals, or has no overstory.

example is the Deardorff reach from RM 35.2 to 35.6, which is virtually the only reach along the entire river that has not been significantly altered by land conversion. The pre-dam floodplain and riparian forests were still intact in the early 1990's and extensively used by herons and egrets as a rookery (Trinity Restoration Associates 1991). Since then, attrition from old-age and fire have eliminated most of the mature cottonwoods, and the floodplain is slowly converting to tree of heaven and grassland. Additionally, as these mature cottonwoods die, a primary seed source dies with them. Restoring cottonwood stands should therefore be an integral component of all channel and floodplain restoration projects.

Valley oaks are also found throughout the Tuolumne River corridor, and are usually the dominant plant in a series. Because of their slow growth, valley oaks are one of the most threatened native riparian species in the corridor and Central Valley. Valley oak regeneration on the Tuolumne River is more successful than the Fremont cottonwoods, partly because valley oaks are not as dependent on fluvial processes for regeneration. Additionally, valley oaks regenerate better on heavier soils with a high silt and clay content. Animals stashing acorns (jays, squirrels) assist valley oak regeneration.

Urban, agricultural, and aggregate extraction land conversion adjacent to valley oak stands have reduced populations of those animals that stash acorns where they could germinate if forgotten, and continual disturbance prevents those acorns that do sprout from maturing. Additionally, the regulated flood flow regime has reduced, if not eliminated floodplain formation processes and the silt and clay deposition floodplains and terraces. There are several pockets of naturally reproducing valley oak stands, but many stands are senescent. Valley oaks appear to be regenerating in the few places within the corridor where acorns are fluvially deposited and in partially shaded stands with fluvial silts and clays intact.

3.4.1.3. Riparian series mapping and riparian inventory

During September and October of 1996 we conducted a field-based inventory of riparian vegetation series within the Tuolumne River corridor from La Grange Dam (RM 52.2) to the San Joaquin River (RM 0.0). Riparian vegetation was mapped by series on low altitude aerial photographs during several weeks of field reconnaissance. This method provided accurate spatial boundaries of vegetation, as well as verified species/series identification. We mapped vegetation on three air photo sequences: 1986 (1:2,400) from La Grange Dam (RM 52.0) to Geer Road Bridge (RM 26.0) enlarged 1993 (1:4,000) from Geer Road Bridge (RM 26.0) to the San Joaquin River confluence (RM 0.0), and 1997 (1:2,000) for off channel riparian areas.

Vegetation was mapped by tracing boundaries around distinct sub-units on the photographs. We also noted the disturbance level of parcels, the type of disturbance (e.g., grazing, urban encroachment, etc), and identified potential riparian restoration and preservation sites. However, we did not differentiate quality of individual stands; degradation was related more to land parcels and land use rather than stand types. We then calibrated aerial photographs to control points common to the existing GIS maintained by the Districts, digitized the riparian series boundaries, and riparian restoration and preservation sites as unique GIS layers.

Not surprisingly, our primary finding was that the total acreage of riparian vegetation in the Tuolumne River corridor has been vastly reduced. Prior to extensive land development there were an estimated 13,000 or more acres of riparian vegetation between La Grange and Modesto. Today less than 2,200 acres remain between La Grange and the San Joaquin River (Table 3-10).

A second finding was a transition between white alder and box elder near Geer Road Bridge (RM 25). White alder is common along the low flow channel in the gravel-bedded zone, but their distribution ends near Geer Road Bridge, and they are replaced by box elder, which continue downstream to the San Joaquin River. This transition is largely due to the decrease in channel slope and transition from gravel bedded to sand bedded substrate. Apparently, alders prefer gravel dominated substrate, while box elders prefer sand dominated substrate. Both tend to occupy a similar hydrologic niche along the low flow channel margins.

We also found that most relic riparian vegetation stands greater than 10 acres were typically within State Park boundaries, the City of Modesto, or Stanislaus County parks. However, these relic stands have not been immune to human disturbance. Roads and campgrounds create openings in an otherwise dense understory, and frequent ground disturbance (vehicular and foot traffic, lawn maintenance) discourages natural regeneration processes. High intensity human activity also discourages wildlife use. Park management often tends to prevent a relic stand from changing, resulting in no new riparian recruitment and continued aging and dying-off of senescent riparian stands. The few remaining relic stands on private property (e.g., Deardorff's at RM 35.2) have considerably more wildlife use, which may be related to less intensive management or disturbance.

Riparian mapping also distinguished vegetation in different geomorphic sub-units. The following descriptions of riparian stands in each sub-reach illustrate these unique characteristics.

3.4.2. Description of riparian vegetation in Sand-bedded Zone

Vegetation in the sand-bedded zone was historically subjected to somewhat different processes than the gravel-bedded zone. Rather than the channel migrating and/or avulsing back and forth between two valley walls, the channel in the sand-bedded zone tended to migrate slowly, increasing the meander amplitude to a pivotal point at which the meander would cut off. This migrational process eroded mature riparian vegetation on the outsides of bends, and built new floodplains on the insides of the bends. As meander bends were pinched off, they created oxbows that were seasonally hydrated by the groundwater table. Oxbows and developing floodplains provided ideal conditions for riparian initiation and growth. The availability of silts and clays on the floodplain created fine-textured soils that could support large stands of valley oaks. These sites might not be disturbed by floods or channel migration for many decades, allowing them to mature into large gallery forests (hundreds of acres) (Figure 2-17 and 2-27). Gallery forests appear to have had almost total canopy closure, creating unique and diverse microclimates in the Tuolumne River bottomlands. Young islands might have cottonwood and valley oak providing the stand structure, and become surrounded by willow thickets. Over time, vines would grow on the maturing overstory trees, and by the time the overstory became senescent or vines had begun to shade out the canopy trees, the river presumably would again erode into the gallery forest and continue the process elsewhere.

Conditions necessary for maintaining these processes, and the riparian vegetation dependent upon these processes, have largely been eliminated. Rip-raping and reduced high flow regime prevent the channel from migrating, such that oxbows and floodplains are no longer created. Several relic oxbow lakes remain as testament to a greater forest that was once present (Figure 2-27), but they are now canal drains and irrigation ponds. Black willow, narrow-leaf willow, and box elder are the only tree species successfully regenerating under contemporary conditions.

Restoration designs should attempt to recreate the dense vegetation that was historically found in the sand-bedded zone; vegetative cover appeared to be complete over most of the zone. Revegetation efforts should attempt to establish complete vegetative cover as soon as possible following planting (within ten years). The Nature Conservancy effectively employs conventional farming techniques on the Cosumnes and Sacramento Rivers, using either variably spaced rows or pseudo sine waves. Cottonwoods should be prioritized because of their fast growth, while valley oaks could be planted between cottonwoods, to eventually grow over the cottonwood canopy.

3.4.2.1. Reach 1: Lower Sand-bedded Reach (RM 0.0 to 10.4)

Most riparian vegetation in the lower sand-bedded reach has been cleared (Figure 2-23 and 2-24), leaving a narrow band one tree-width wide between agricultural lands and the river. These strips of one tree width sometimes link larger relic valley oak and cottonwood stands. From the confluence with the San Joaquin River to RM 10.4 there are few large (>5 acres) stands of riparian vegetation, with only a small percentage of valley oak (Appendix B, Maps 16-19). The newly acquired San Joaquin Wildlife Refuge at the downstream end of the reach contains some of the best remaining riparian forests in the San Joaquin basin.

Over the past few decades, bank rip-rap and increasingly regulated flow regimes have stabilized the banks in what was once a frequently migrating channel. Stabilization encouraged a trapezoidal channel geometry, prevented channel migration in most reaches, reduced natural riparian regeneration, and eliminated meander cutoffs (and associated oxbows). Riparian regeneration in this area is limited to local pockets in the rip-rap, or on the upper edge of levees. Relic valley oak and cottonwood stands remain around old oxbow channels, and represent the greatest cover and structural diversity between the City of Modesto and the river's confluence with the San Joaquin. On the Mapes Ranch at RM 0.5, where the channel is still migrating and high spring flows can access a floodplain, cottonwoods are regenerating. This site is discussed in more detail in Section 3.4.4.1. Remnant stands should be longitudinally and laterally enlarged, and eventually connected with the Tuolumne River Regional Park (upstream) and the San Joaquin Wildlife Refuge downstream.

3.4.2.2. Reach 2: Urban Sand-bedded Reach (RM 10.5 to RM 19.3)

This reach is dominated by the Tuolumne River Regional Park, and urban expansion into the Tuolumne River corridor in areas surrounding the Park. Because of continued urban expansion, riparian vegetation outside the Tuolumne River Regional Park is dwindling. Outside of the park, riparian vegetation consists of small (<2 acres) dense bands of narrow-leaf willow along the low water margin, interspersed with senescent Fremont cottonwoods (Appendix B maps 13-16). Occasionally a valley oak delineates the break in slope between urban development and the historic bankfull channel. Urban encroachment and a somewhat narrow valley width have confined the channel, and migration is minimal. Although exotics are common throughout the river corridor, they are most pronounced around localized areas of urban development.

Tuolumne River Regional Park, in the heart of Modesto, is the largest tract of riparian vegetation in this reach. The park mostly consists of relic of valley oak stands, the largest contiguous stands of valley oaks in the sand-bedded zone. Riparian management by the Parks Department has included non-riparian plantings. Lawn cultivation and human foot traffic (along with loss of flood hydrology) have prevented natural regeneration. A restoration plan for the Tuolumne River Regional Park has recently been developed, which recommends that riparian restoration play a primary role in future Regional Park improvements (Dahlin 1997). The Regional Park intends to own river bottomland within Modesto and Ceres city limits and create a continuous riparian parkway through the Cities of Modesto and Ceres. Reaches downstream should be restored to eventually connect the Regional Park with the San Joaquin Wildlife Refuge at the mouth of the Tuolumne River.

3.4.2.3. Reach 3: Upper Sand-bedded Reach (RM 19.3 to 24.0)

Similar to the downstream sand-bedded reaches, this reach contains few large stands (>5 acres) of valley oaks and cottonwoods. Narrow-leaf willow series dominates riparian vegetation (Appendix B maps 11-13). River confinement between the bluffs is more pronounced in this reach, as is narrow-leaf willow encroachment into the active channel. Along the base of the bluffs, stands of valley oak and mixed willow series thrive, presumably sustained by seeps along the base of the bluffs. Continued agricultural encroachment, urban development, and the reduced high flow regime discourage riparian vegetation from regenerating.

3.4.3. Description of riparian vegetation in Gravel-bedded Zone

As discussed in Chapter 2, the historical high flow regime, low flow regime, adequate sediment supply, and bankfull/floodway confinement provided the "checks and balances" to prevent riparian vegetation from establishing a dense jungle between valley wall margins. Riparian vegetation tended to establish on areas with heavy soils (silts) and shallow water tables. In the gravel-bedded zone, these areas were at the base of bluffs and terraces where groundwater moistened silty soils, or in remnant channels, side channels, or floodplain surfaces where topographical depressions created zones close to the groundwater table. Riparian vegetation tended to key into these two microclimates, resulting in patchy distributions and abundances (Figures 2-19). These patches were true riparian forest. Between patches, floodplains were primarily grasslands, with occasional valley oaks.

Today, little of the original vegetation remains in the gravel bedded reach due to agricultural encroachment and aggregate extraction; all regenerating hardwoods are contained within the narrow 9,000 cfs floodway. Nearly all areas that naturally supported riparian forests have been mined, grazed, and/or farmed. The only native riparian species that has benefited from land use activities and flow/sediment regulation is narrow-leaf willow. Reproductively they are very aggressive: underground runners and plant fragments give narrow-leaf willows an incomparable ability to reproduce independent of fluvial processes. As a result, much of the gravel-bedded reach not subject to continual human disturbance has narrow-leaf willow encroachment. Encroachment is so extensive in some areas that the channel cannot migrate. Riparian regeneration also is prevented in many areas by extensive cattle grazing.

Restoration designs within the gravel-bedded zone should reflect riparian vegetation's patchiness; complete vegetative cover did not naturally occur due to soil texture and moisture variations. Because of the natural spatial variation in vegetation, plant series should be planted in patches, leaving open space in between the patches. Special attention should be given to springs, seeps, and the summer ground water elevation, because we can target revegetation in these areas that will improve the long term success of riparian revegetation efforts.

3.4.3.1. Reach 4: In-channel Gravel Mining Reach (RM 24.0 to 34.2)

Primary impacts to riparian vegetation is from in-channel gravel mining and cattle grazing, which have reduced the riparian corridor width and species diversity from historic conditions. Consequently, riparian vegetation regeneration has been eliminated, other than asexual reproduction by narrow-leaf willow. The diversity in riparian series types has also decreased (Appendix B Maps 7-11). For example, between RM 29.0 and 34.2, over 90% of mapped vegetation belongs to mixed willow or narrow-leaf willow series. Valley oaks and cottonwoods are isolated individuals, or stands with no connection to other riparian stands. Exotic species cover is extensive, and in some locations (RM 25.0) cover the entire right bank for over 1,500 ft.

The downstream end of this reach marks the transition from gravel-bedded river to a sand-bedded river. A corresponding plant series transition correlates with this change in substrate and channel slope. White alder series, common in gravel-bedded reaches upstream, becomes increasingly less common in the gravel-bed/sand-bed transition, and is eventually replaced by box elder downstream. White alder and box elder occupy channel margins in riffles and the outsides of meander bends.

At the upstream extent of this reach (RM 31.8 to 34.2) where the channel is confined against bluffs, land use in the corridor has been minimal because of the narrow corridor width. This has resulted in the largest contiguous stand of valley oaks on the Tuolumne River.

3.4.3.2. Reach 5: Gravel Mining Reach (RM 34.2 to 40.3)

Off-channel aggregate extraction and some in-channel aggregate extraction have dictated where riparian vegetation can grow in this reach, creating a unique spatial pattern (Appendix B, maps 5-7). Pre-NDPP floodplains were mined, removing all riparian vegetation and leaving off-channel pits isolated from the Tuolumne River by dikes. Riparian regeneration is almost exclusively narrow-leaf willow and white alder, inhabiting low-water margins of the dikes along both banks. Aggregate extraction has left solitary valley oaks or cottonwoods often surrounded by exotic plants. The south bank has been severely disturbed, with lengths of unvegetated channel commonly exceeding 1,000 ft. The primary limiting factor in this reach is floodway space; dike setbacks and floodplain restoration are essential to increasing riparian vegetation in this reach.

3.4.3.3. Reach 6: Dredger Tailing Reach (RM 40.3-45.5)

This reach is the widest among the gravel-bedded reaches. Vegetation flourishes along the channel and in hollows created by dredger tailings (Appendix B Maps 4-5). Turlock Reservoir State Park (RM 41.0) contains a large relic valley oak/cottonwood stand (> 5 acres), perhaps the best example of mature riparian vegetation structure and species composition in the gravel-bedded zone. These cottonwood and valley oak stands are highly productive and could be a seed source for future restoration. This is the only reach where multiple age classes of cottonwoods were documented, suggesting that little regeneration is occurring. Younger age classes are establishing primarily between rows of dredger tailing mounds where groundwater is near the surface. However, there is little continuity between stands because these mounds tend to separate the patches of riparian vegetation.

A dense thicket of arroyo willow and/or narrow-leaf willow within the historic bankfull channel is the only other regenerating riparian vegetation. In a few areas along this reach, cattle grazing has prevented riparian regeneration and denuded the banks. The understory and gaps within relic Fremont cottonwood and valley oak stands are being invaded by tree of heaven and giant reed. When the NDPP was constructed, much of the construction aggregate was removed from Reaches 6 and 7. Removing the dredger tailings lowered surfaces adjacent to the river to near contemporary floodplain elevations. There is tremendous opportunity for both artificial and natural riparian regeneration in this reach.

3.4.3.4. Reach 7: Dominant Spawning Reach (45.5-52.1)

The downstream section of this reach is confined by valley walls and terraces (RM 45.5 to RM 47.5), that supports a relatively narrow band of riparian. The section upstream of Dominici Creek widens into a 1,000 ft or wider corridor, and again narrows at RM 50.5 at the "official" beginning of the Sierra Nevada foothills. The riparian corridor width varies with valley width (Appendix B, Maps 1-3). Dredger tailings were also removed for the NDPP, and subsequent channel reconstruction in 1971 created a wide spawning channel with low confinement and frequently inundated floodplain. The channel morphology has not changed significantly since 1971, and riparian vegetation is typified by strips of alder and narrow-leaf willow along the channel margins, with scattered patches of narrow-leaf willow in remnant dredger tailing pits. Senescent Fremont cottonwoods are also present, but younger age classes of cottonwoods and valley oaks are not. The middle section of the reach has considerable potential for riparian restoration due to low, frequently inundated floodplain surfaces, and potential elimination of cattle grazing.

Upstream of Old La Grange Bridge (RM 50.5), the Tuolumne River is confined to a bedrock valley. Riparian vegetation persists in hollows and cracks along the valley walls, and does not have the wide areal extent observed downstream. Upland plant series including interior live oak, California buckeye, and blue oak stands dominate the narrow riparian corridor within the bedrock valley.

3.4.4. Riparian vegetation relationships to contemporary and historic fluvial geomorphology

As discussed in Chapter 2, there are strong species-specific relationships between riparian vegetation, hydrology, soils, and geomorphic surfaces. Flow and sediment regulation, combined with extensive land use, often obscures or destroys these natural relationships. If flow and sediment regulation is so severe that the channel cannot adjust its dimensions, geomorphic surfaces (bars, floodplains, and terraces) are fossilized by riparian plant encroachment. In most alluvial rivers with unimpaired flow regimes, floods with recurrence intervals of 1.5 to 2.5 years typically inundate floodplains. Floods of this recurrence interval approximate bankfull discharge. We used this relationship in Chapter 2 to illustrate how the reduced flood regime has affected riparian plant series initiation and establishment. Pre-NDPP floodplain surfaces that are no longer inundated cannot support floodplain vegetation regeneration.

We compared relic and contemporary stands with past and present fluvial geomorphic conditions in which they live. These relationships are useful in future channel and riparian restoration projects because the revegetation can be scaled according to the design discharges and planform morphology; similar to scaling down channel morphology to match a reduced flow regime. Vegetation transects were used to illustrate these relationships.

3.4.4.1. Vegetation transects

We surveyed a transect in the upper gravel-bedded reach, the upper sand-bedded reach, and lower sand-bedded reach. Each cross section had riparian regeneration and represented different channel morphologies. Our objectives were to: (1) observe riparian and fluvial geomorphic relationships that could be used for future restoration designs and (2) determine if the channel morphology and riparian initiation patterns have adjusted to the post-NDPP regulated flow regime.

The transect sampling sites were located at:

- Basso Bridge transect (RM 47.0 in Reach 7), 0.5 miles downstream of Basso Bridge, (Figure 3-33).
- Santa Fe transect (RM 22.5 in Reach 3), 0.3 mile upstream of Santa Fe Bridge at Lakewood Memorial Park (Figure 3-34).
- Confluence transect (RM 0.5 in Reach 1), 0.5 miles upstream of the confluence with the San Joaquin River on the USFWS National Wildlife Refuge (Figure 3-35).

Each transect was established perpendicular to high flow direction. Vegetation was sampled within a 10 ft band upstream and downstream of the transect. Transect sampling included measurements of stand age, diameter and tree heights greater than 6 inches breast height diameter (DBH), and species. Voucher specimens of common native riparian and exotic hardwoods were collected and have been archived by TID and Fresno State University. The Confluence transect was surveyed to 1929 NGVD as established by the Department of Water Resources during their 1997 flood elevation surveys. The other two transects used a relative datum of 100.00' on the upper left bank transect headpin. Water surface elevation, flood debris elevation, and certain individuals trees and plants were surveyed.

One task was to associate riparian stand characteristics with discharges that inundated distinct geomorphic surfaces. We used flood debris, high flow water surface profiles, and U.S. Geological Service discharge rating tables from the closest gage to quantify the stage and discharge for inundation. For the Basso Bridge transect, we used the La Grange gage (USGS Station # 11-289650) and our Basso Bridge water surface profile survey (5,400 cfs); for the Santa Fe transect and the Confluence transect, we used the Modesto gage (USGS Station # 11-290000), although water surface at the confluence transect is often governed by flows in the San Joaquin River.

Basso Bridge Transect (RM 46.0)

We chose the Basso Bridge transect because of relic pre-NDPP, valley oak, and Fremont cottonwood stands on both banks and because we observed some post-NDPP cottonwood and valley oak regeneration (Figure 3-36 and 3-37). Mining activities prior to the 1937 aerial photo series removed all riparian vegetation on the left bank but avoided a few valley oaks on the right bank. By the 1950 photo series, riparian vegetation was recovering from mining. Cottonwood and valley oak stands were evident on aerial photographs. In the late 1960's the left bank was excavated to near a post-NDPP floodplain elevation (a 5,400 cfs water surface and 2.5 year flood) for NDPP construction, and removal of left bank dredger tailings avoided most mature riparian vegetation.

Riparian vegetation along this transect consists of Fremont cottonwoods, valley oak, and narrow-leaf willow series. Mature Fremont cottonwoods sit atop "islands" left when the dredger tailings were removed around the cottonwoods on the left bank (Figure 3-36). Valley oaks and cottonwoods are regenerating on the new "floodplain" surface on the left bank; however, the right bank is heavily grazed, preventing riparian hardwood regeneration even though it is at an elevation approximating a post-NDPP floodplain. The mature valley oak and cottonwood stands on this transect are very healthy. The valley oak canopy is contiguous and has approximately 60% canopy closure (Figure 3-37), but mature cottonwoods are not close enough to each other to form a contiguous and closed canopy.

The rooting elevations for valley oak and cottonwoods of different cohorts (pre- versus post-NDPP establishment) shows that pre-NDPP cottonwoods initiated on pre-NDPP floodplain surfaces (inundated by 8,400 cfs, a 1.5 year recurrence post-NDPP flood) (Figure 3-36). Post-NDPP cottonwoods initiated between the 5,600 cfs water surface elevation and the 8,000 cfs water surface, which are 2.7 year and 5.6 year post-NDPP floods respectively. Channel migration does not occur in this reach due to riparian encroachment and reduced high flow regime, and post-NDPP "floodplain" surfaces are not fluvially formed (but are excavated surfaces). Therefore, post-NDPP riparian regeneration is occurring on a artificially constructed surface, which happens to inundate during floods slightly larger than the 1.5 year flood. Valley oaks, regardless of cohort, appear to regenerate at a variety of elevations above the 5,600 cfs water surface elevation.

Santa Fe Transect (RM 22.5)

We chose the Santa Fe transect because of a large stand (4.25 acres) of mature Fremont cottonwoods on a pre-NDPP floodplain on the south

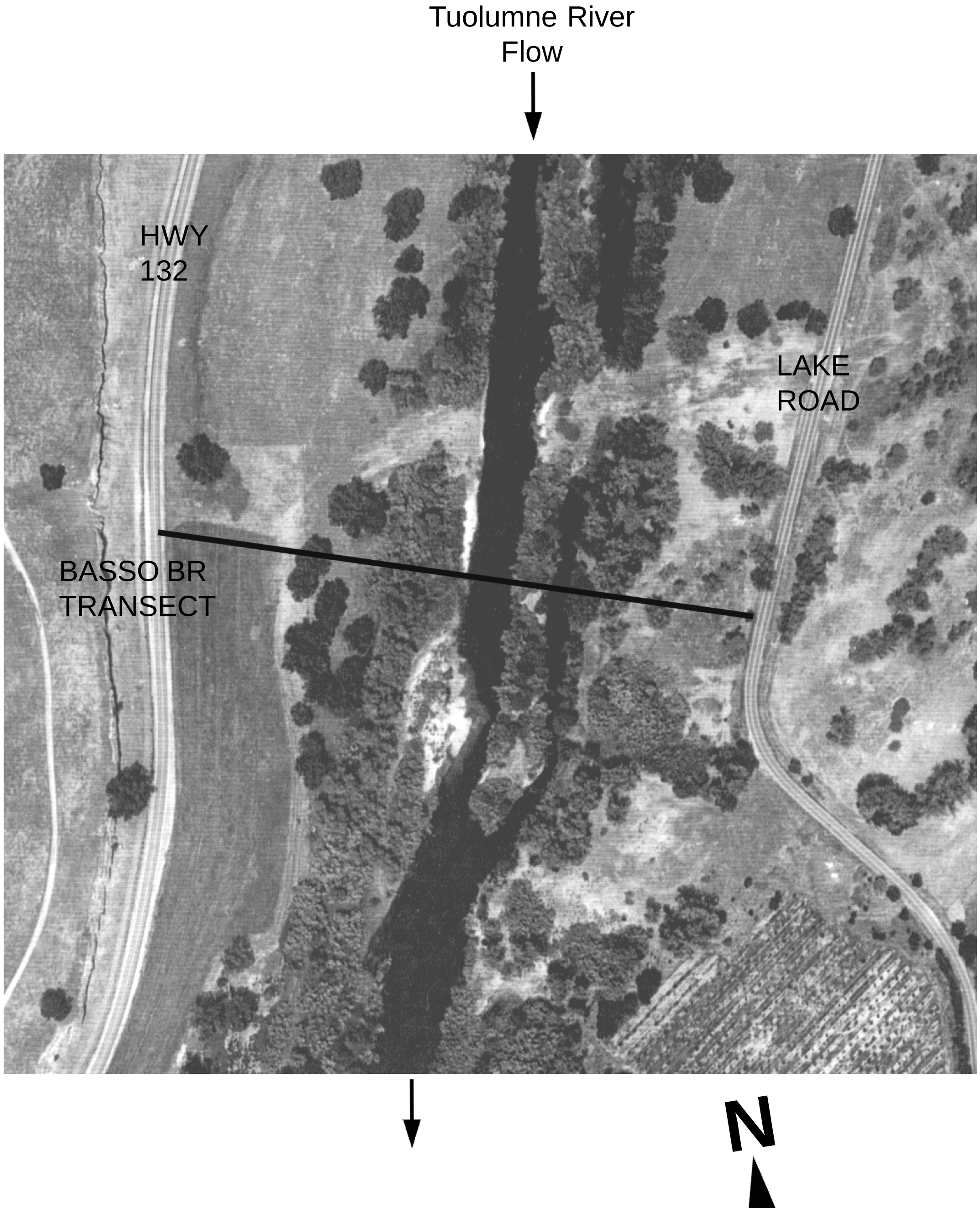


Figure 3-33. Basso Bridge vegetation transect location (RM 47.0), shown on 1993 aerial photograph (approximate scale: 1" = 350').

bank, and because valley oaks and cottonwoods are regenerating on a newly forming floodplain (Figures 3-34, 3-38, 3-39, and 3-40). The 1937 and 1950 air photos show an orchard on the south bank floodplain; 1963 and 1974 photos show the orchard had been removed. At some point between 1963 and 1974, a series of events (predicated on the fallowing old orchard) produced a successful cohort of cottonwoods to establish. The transect shows the pattern of pre- and post-NDPP riparian regeneration, species composition, stand structure, and canopy architecture because it is one of the few sites where the reduced hydrologic regime has formed post-NDPP floodplains and the riparian

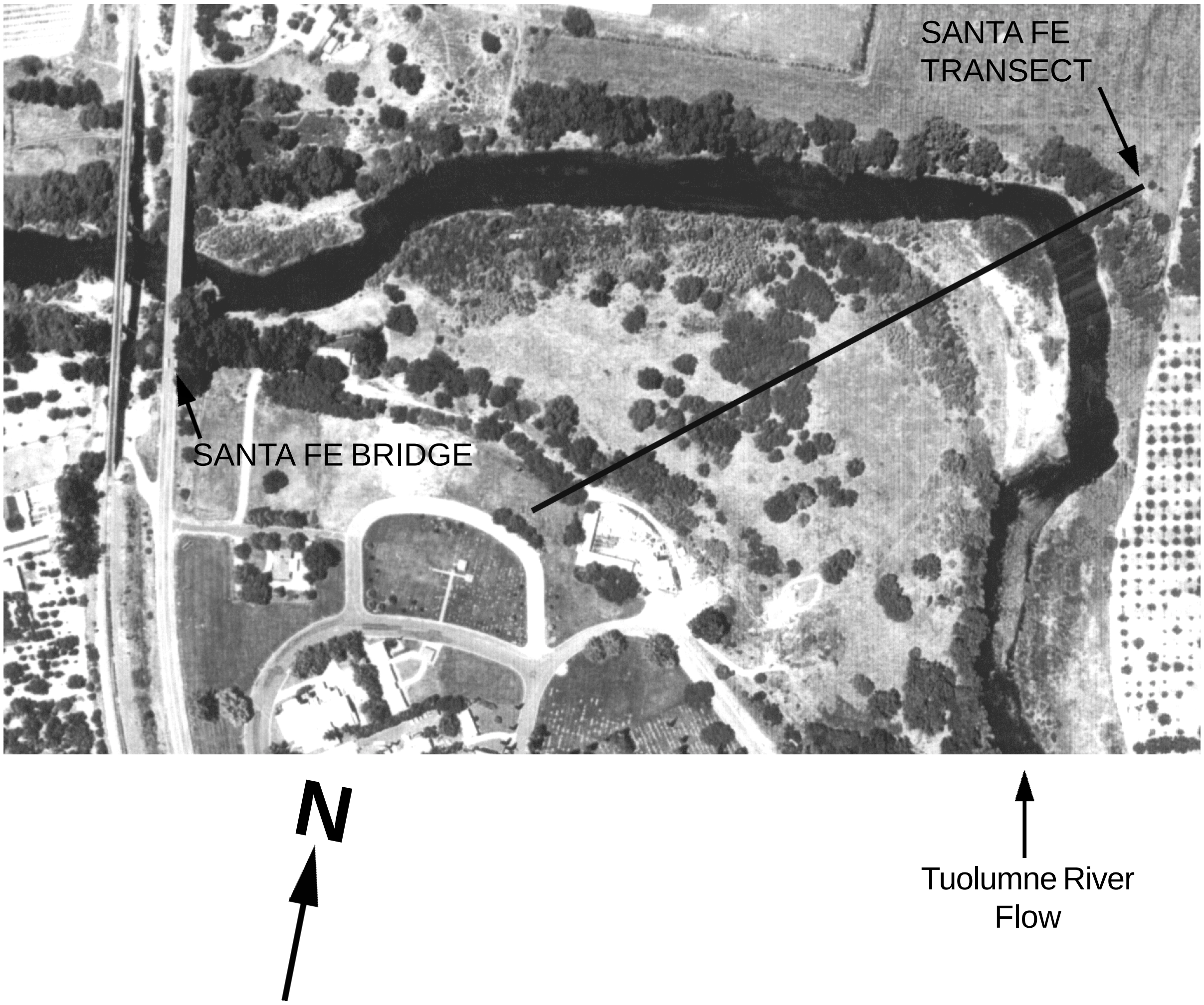


Figure 3-34. Santa Fe vegetation transect location (RM 22.5), shown on 1993 aerial photograph (approximate scale: 1" = 350').

vegetation has partially regenerated. Riparian vegetation along the transect is diverse, consisting of four series: narrow-leaf willow, box elder, Fremont cottonwood, and valley oak.

Currently, riparian regeneration is restricted to the left bank between the low water edge and the mature box elder stand (Figure 3-38); an area 250 ft wide representing the zone of developing post-NDPP floodplain. This observation suggests that riparian hardwood regeneration can occur on developing floodplains that are inundated by floods of 1.5 to 5 year recurrence intervals under the post-NDPP high flow regime. In other words, the channel and riparian vegetation appears to be scaling down to the post-NDPP flow regime at this location. When the transect was originally surveyed in 1996, cottonwood seedlings initiated close to the summer water surface and valley oaks were establishing further up the bank, but still well within the post-dam bankfull channel. When we resurveyed the transect after the January 1997 flood, the cottonwood seedlings had been killed by the flood, but the establishing valley oaks were still present.

Canopy closure within the mature Fremont cottonwood stand is almost 100% and is contiguous. There is no liana (vines) development within the stand, and valley oaks in the area have not reached a "weeping" habit indicative of older undisturbed stands. The Fremont cottonwood understory (i.e., shrub and ground vegetation layer under the cottonwoods) is open with only grasses in the ground layer. Along the bluff walls, superimposed over the cottonwood's

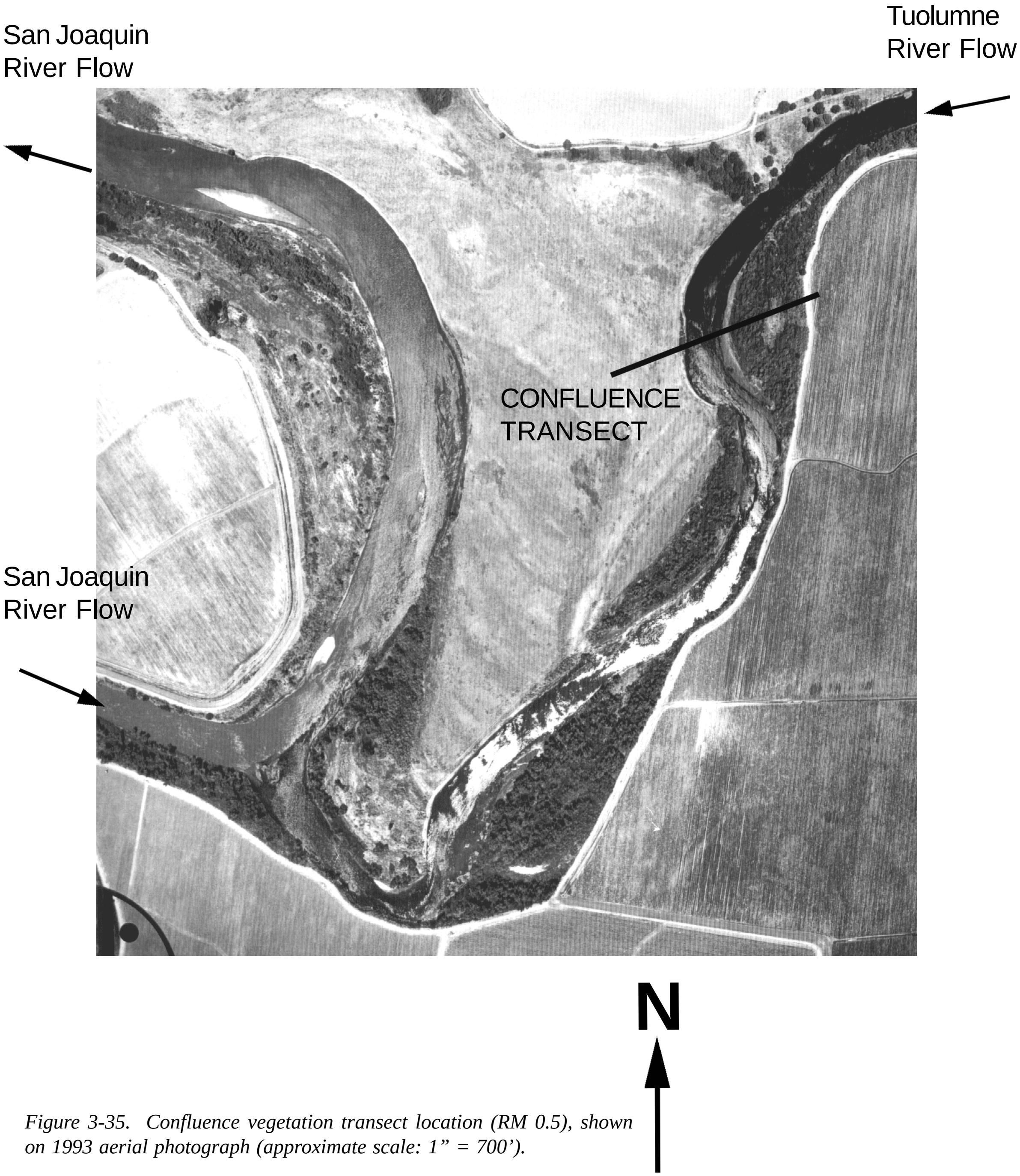


Figure 3-35. Confluence vegetation transect location (RM 0.5), shown on 1993 aerial photograph (approximate scale: 1" = 700').

canopy, are mature valley oaks. On the historic floodplain margin towards the bankfull channel, a 20 ft tall, dense narrow-leaf willow thicket transitions into a mature box elder stand (Figure 3-39). The narrow-leaf willow canopy is dense, with a short break before the open box elder canopy. Another stand of narrow-leaf willow is growing on the evolving point bar near the low flow water surface.

This transect shows that pre-NDPP riparian vegetation established and matured on the historic floodplains, while younger post-NDPP riparian vegetation is regenerating on post-NDPP floodplains, which are within the pre-NDPP bankfull channel. These data suggest that regeneration can occur at other reaches, but on a smaller scale within the historic bankfull channel, and perhaps only at sites where channel migration allows the channel to re-form a post-NDPP bankfull channel

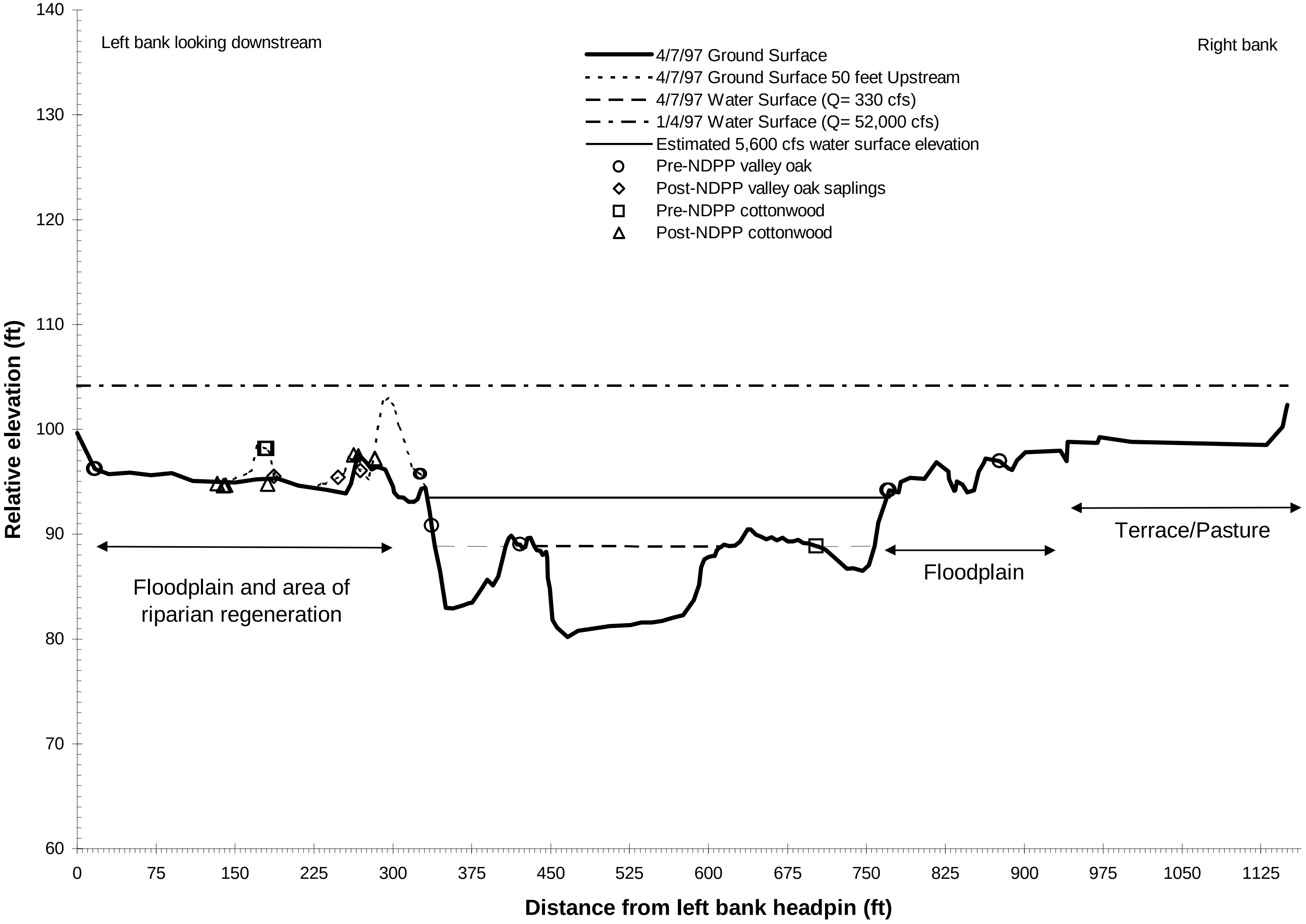


Figure 3-36. Cross section servey and location of riparian vegetation at Basso Bridge vegetation transect (RM 47.0)

Figure 3-37. Basso Bridge vegetation transect looking from left bank toward right bank.

and floodplain. We do not expect cottonwoods to regenerate on pre-NDPP floodplains (which are now terraces) because contemporary flows are inadequate to create gaps in the existing vegetation (to establish seed beds) and maintain soil moisture during the seeding initiation period. There are few reaches that are migrating and forming a smaller two-stage channel under the contemporary flow regime.

Confluence Transect (RM 0.5)

The Confluence transect exemplifies the lower sand-bedded reach riparian corridor. We chose this reach because the landowner had ceased cultivating the north bank floodplain, allowing riparian initiation to occur and the river to migrate. A dike confines the river on the left bank, with a tomato field behind it and a dense thicket of willows growing between the dike and the river (Figure 3-41 and 3-42). This site was an actively building point bar surrounded by dense riparian forest before agriculture cleared the area (Figure 2-27). Floodplain surfaces in this reach continued to regularly flood after NDPP was completed, but agricultural cultivation continued, preventing riparian regeneration from occurring. After cultivation and bank protection ceased, the channel resumed migrating towards the right bank, creating a new point bar and incipient floodplain surface on the left bank.

Relating vegetation establishment elevations and geomorphic surfaces with high flows is difficult in the lower sand-bedded reach because water surface elevations depend on both Tuolumne River flows and San Joaquin River flows. When the San Joaquin River floods, the Tuolumne River becomes a sluggish backwater. When Tuolumne River flows exceed 8,500 cfs, all surfaces begin to become inundated. For Tuolumne River flows less than 7,000 cfs, the floodway in this reach is 600 ft; when flows exceed 8,500 cfs, the floodway exceeds 3,000 ft.

There are no canopy forming trees along the Confluence transect. The dominant vegetation along the transect consisted of Goodding's black willow and narrow-leaf willow. These species were concentrated within the bankfull channel (Stations 0 to 350 on Figure 3-41). Box elder and cottonwoods were present on the transect, but box elder was only associated with the mature

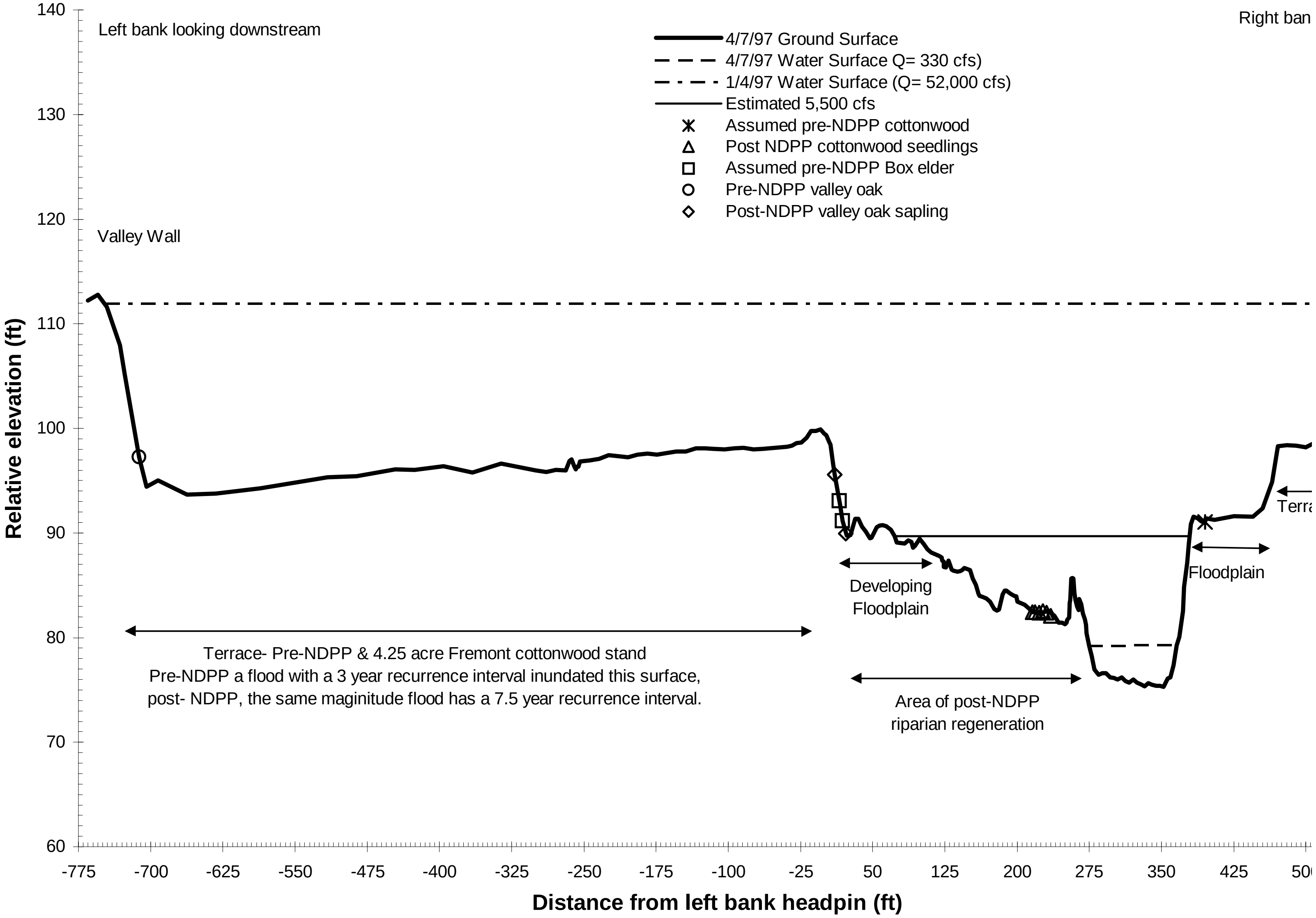


Figure 3-38. Relationship of cottonwood and valley oak trunk diameters to rooting elevations at Zanker model transect.

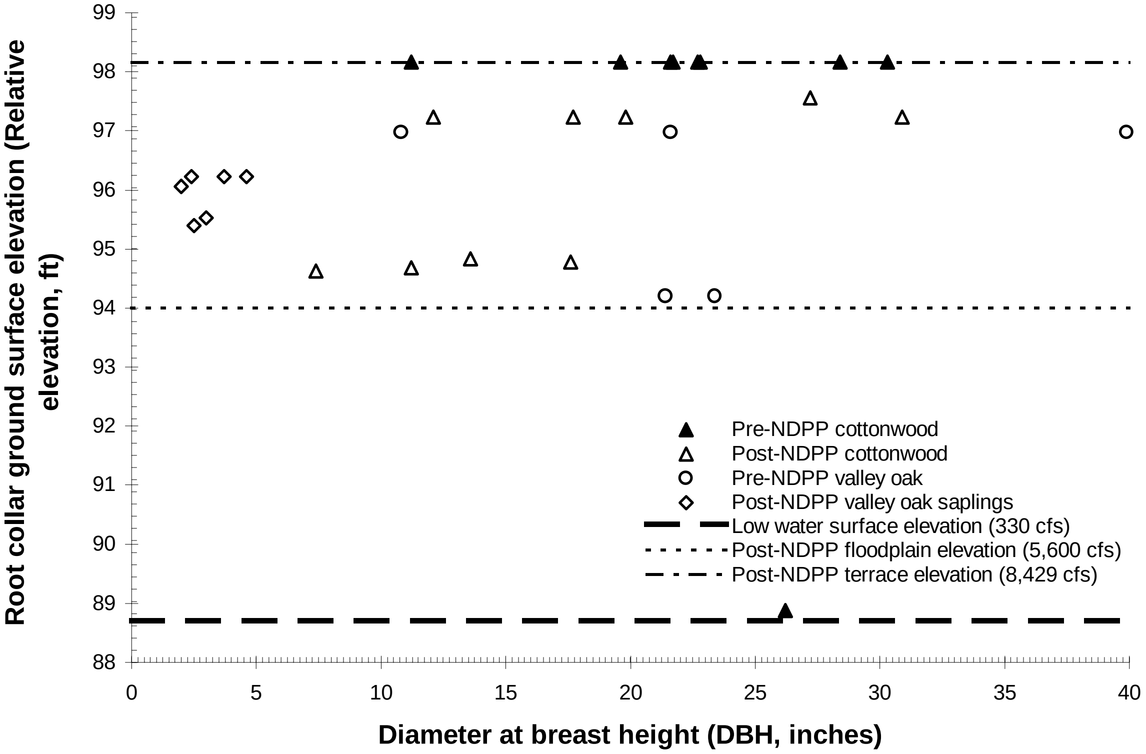


Figure 3-39. Cross section survey and location of riparian vegetation at Santa Fe vegetation transect (RM 22.5).

black willow stands on the south bank. Narrow-leaf willow creates a dense jungle along the south bank, firmly anchoring a developing point bar deposit. Behind the narrow-leaf willow jungle there are Goodding's black willow trees with a box elder understory; no trees grow over 20 feet high.

Cottonwoods were establishing on the north bank fallow field. This fallow field was recently acquired by USFWS as part of the San Joaquin River Nation Wildlife refuge (Figure 3-41). Exotic annual plants currently dominate this surface, but young (<6 year) establishing cottonwoods are beginning to appear over the exotic plants. Continued high flow events during the cottonwood seeding period will encourage more initiation, and as the cottonwoods mature and produce seeds, they should out-compete the shade intolerant exotic annual plants, and encourage other native riparian vegetation to initiate. In stark contrast to the south bank, the north bank mainly consists of annual exotic plants and young Fremont cottonwoods, none reaching a height of more than 7 feet.

Using the Modesto gaging station flood frequency curve (and assuming independence from the San Joaquin River flows), the north bank fallow field is inundated by a 3.0 year post-NDPP flood. In reality, San Joaquin River floods would increase inundation frequency. The south bank point bar is inundated very frequently, which may explain why only willows and box elders (rather than cottonwoods and valley oaks) are regenerating on the bar.

Transect summary

Our transect surveys suggest that riparian vegetation is dominated by relic vegetation on pre-NDPP floodplains and terraces, and small patches of newly established vegetation on the few post-NDPP floodplains that have formed. Most of the recently established vegetation occurs along the low flow channel margins. Pre-NDPP vegetation reflects a larger hydrologic scale. Recall that the 1.5 year and 5 year flood decreased from 8,400 cfs and 25,000 cfs prior to NDPP, to 2,600 cfs to 7,000 cfs after NDPP. Riparian vegetation responded by growing in a narrow band close to

Figure 3-40. Photographs of Santa Fe vegetation transect (RM 22.5), looking from right to left bank at newly forming floodplain in foreground of bottom photograph, and at pre-NDPP floodplain with mature cottonwoods in top photograph and background of bottom photograph.

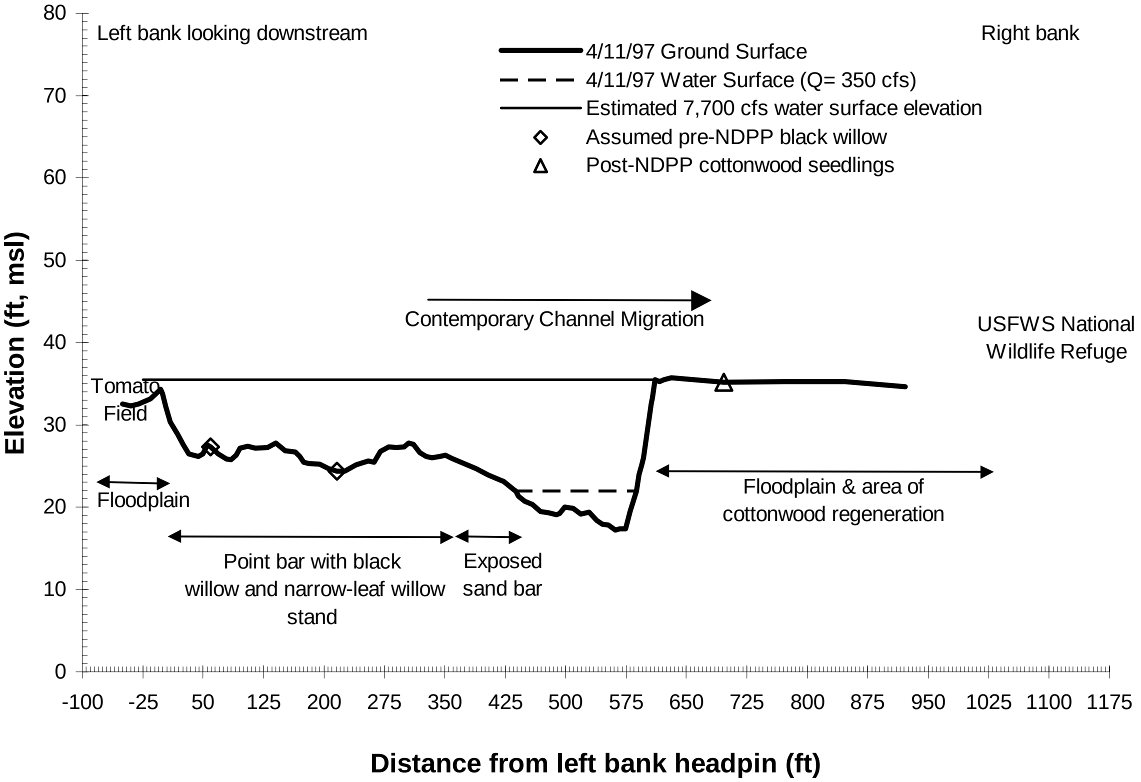


Figure 3-41. Cross section survey and location of riparian vegetation at Confluence vegetation transect (RM 0.5).

the narrower channel. We hypothesized that riparian regeneration (particularly Goodding's black willow and Fremont cottonwood) depends on three fundamental processes: a migrating channel that creates floodplain surfaces, flood inundation occurring between 1.5 to 5 years, and a gently receding snowmelt hydrograph limb.

Elimination of floods exceeding 10,000 cfs after the NDPP allowed narrow-leaf willow, box elder, and white alder to encroach onto the low flow channel, while removal of the snowmelt hydrograph resulted in xeric conditions on pre-NDPP floodplains. As a result, the riparian corridor width narrowed and pre-NDPP cohorts of Fremont cottonwood and valley oak still alive are beginning to die of old age. Riparian regeneration occurs only where soil and microclimatic environments meet each hardwood species' physiologic requirements

3.4.4.2. Planform vegetation patterns

Examining pre-NDPP vegetation patterns and selected post-NDPP patterns from our transects and riparian inventory maps allows us to hypothesize planform riparian vegetation patterns that can be used in future riparian revegetation designs. Most relic valley oak stands appear to grow above the 60,000 cfs water surface elevation, although there was still considerable regeneration between the 5,600 cfs water surface elevation and the 60,000 cfs water surface elevation, particularly in the gravel-bedded zone. Valley oak stands historically preferred terraces and floodplains areas that had heavy silt/clay soils. Today, valley oaks are only capable of regenerating on contemporary floodplain surfaces and pre-NDPP floodplains (now functional terraces).

Relic Fremont cottonwood stands grow above the 8,000 cfs water surface elevation on pre-NDPP floodplains, with most growing above the 14,000-16,000 cfs water surface elevation. Contemporary cottonwood regeneration is dysfunctional, restricted to isolated reaches where channel migration occurs, surfaces that have been lowered when removing dredger tailings, and pond margins among dredger tailing piles. Under natural

Figure 3-42. Photographs of Confluence vegetation transect (RM 0.5), looking from right to left bank at newly forming floodplain on bottom photograph, and looking from left to right bank at eroding bank on outside of meander bend, top photograph.

conditions, cottonwoods establish on floodplains where soil moisture and texture are "adequate". Adequate conditions are created by: topographic depressions on floodplain surfaces that are close to groundwater tables, snowmelt hydrographs that moisten floodplain soils during seeding periods, and exposed silty soils that retain moisture. High flow scour channels, oxbows, and side channels are common planform features where cottonwood forests historically occurred.

Goodding's black willow is a tree willow tolerant of a drier environment. Goodding's black willow tends to survive where agricultural or aggregate extraction encroachment has reduced riparian vegetation to one tree width. Naturally, however, they tend to grow near the bankfull channel elevation (on upper bars and lower floodplains), and grow well in topographic depressions in the floodplain. Black willow grows below the 8,500 cfs water surface elevation upstream of Dry Creek, and below the 12,000 cfs water surface elevation below Dry Creek.

White alder, narrow-leaf willow, and box elder are the primary species that have flourished under regulated flow and sediment conditions. These species grow along the channel margins between the 300 cfs and the 6,000 cfs water surface elevations. Most narrow-leaf willow establishes below the 6,000 cfs water surface elevation and grows down to the summer low water surface (<300 cfs). Box elder and white alder grow in similar bank positions, typically slightly higher than the narrow-leaf willows. Box elder occurs along channel margins in the sand-bedded zone and white alder in similar location in the gravel-bedded zone. White alder tends to favor channel margins along riffles and the outside of meander bends, and with narrow-leaf willow, is the dominant species causing riparian encroachment. Because white alder and box elder grow so close to the low flow channel, the increased summer flows and recent root collar burial during high flows has caused considerable mortality, particularly in the sand-bedded zone.

3.4.5. Summary

There are no true riparian "model" sites remaining in the Tuolumne River corridor developing blueprint riparian restoration designs. A few sites have relic riparian stands and limited natural regeneration from which we inferred relationships between fluvial geomorphology and riparian plant ecology. All model transects showed regeneration of certain species, and species composition was indicative of the hydrologic and morphologic conditions within that specific river reach. Transect and planform interpretation was evaluated based on how changes in hydrology may have affected riparian regeneration. We documented pre-NDPP cottonwoods and valley oaks occupying pre-NDPP floodplains and terraces. However, slow or non-existent morphologic adjustment to the post-NDPP high flow regime, especially in the gravel-bedded zone, has prevented riparian vegetation from re-establishing those characteristic relationships. In the sand-bedded zone, particularly those where channel migration has occurred, some incipient point bars and floodplains are beginning to be re-colonized with the expected riparian species. However, many reaches of the sand-bedded zone are armored with rip rap or concrete rubble, and riparian regeneration is sparse.

3.4.6. Riparian limiting factors

Due to land use encroachment, much of the Tuolumne River riparian corridor is only one tree wide along each bank. Occasionally, where land use has not significantly disturbed the channel, relic riparian vegetation fragments of a much larger ecosystem are observable, and are indicative of pre-NDPP hydrologic regime. Currently the primary limiting factors preventing riparian plant regeneration in the Tuolumne River riparian corridor are: (1) continued agricultural and urban encroachment into the riparian zone, (2) reduced high flow magnitude and duration, and (3) reduced silt production from the upper watershed. Because the watershed downstream of La Grange Dam is primarily composed of sandy loams, surface erosion in the watershed produces lots of sand, but minor amounts of silt. Silts retain moisture on floodplains better, whereas sand drains much more quickly. Additionally, the continued reduction in high flow magnitude and duration (particularly during the snowmelt runoff period when seed dispersal occurs) has limited channel migration, floodplain building, and floodplain inundation. These factors harm riparian species that reproduce primarily by seed (e.g., valley oaks, cottonwoods, alders, and Goodding's black willow), but favor riparian species that reproduce primarily asexually (e.g., narrow-leaf willow, arroyo willow).

3.4.7. Recommendations

Series that should be prioritized in restoration design are ones in which the "Nature Conservancy Habitat Status Index" ranking ends with "0.1" (Appendix B), including Fremont cottonwood, valley oak, and buttonbush series. Cottonwood and valley oak series are particularly important because of dramatic losses to agriculture, urban encroachment, and aggregate extraction. Cottonwood and valley oak series once provided substantial overstory habitat for birds (egrets, herons, osprey, bald eagles, and others), while the dense understory provided habitat for rodents (in particular the endangered riparian brush rabbit). These series, particularly the cottonwoods, are not substantially reproducing naturally due to land uses and lost fluvial processes. Additionally, blue elderberry series should be prioritized for preservation and restoration because it provides critical habitat for the endangered valley elderberry longhorn beetle.

Valley oak revegetation should be a strong component of future channel and floodplain restoration projects. The primary drawbacks to valley oak revegetation are the high costs per plant, their slow growth rate, and high attrition rate (which is partly a result of their slow growth). Revegetation efforts should focus on cottonwood revegetation and native plant recruitment on floodplain surfaces first, with valley oak revegetation on the upper floodplain and terrace surfaces given second priority.

The riparian corridor can be restored and maintained, but will require improved high flow events and will exist at a scale smaller than existed before the NDPP. We have established that riparian vegetation requires sediment, floods, and space to perpetuate its composition and structure. Fundamental Restoration Plan components required to restore the integrity of riparian vegetation will be:

1. Develop a minimum 500 ft wide riparian corridor and floodway along the entire river that is protected by conservation easements, private ownership, and/or public ownership.
2. Preserve remaining valley oak and Fremont cottonwood stands to provide future seed sources (e.g., the valley oak stand at RM 38.1-34.2, valley oak and cottonwood stands at RM 47.3, the cottonwood stand at RM 6.8).
3. Reconstruct floodplains and terraces at an elevation inundated by flows exceeding 4,000 cfs to 6,000 cfs.
4. Incorporate silt importation on floodplain restoration projects wherever possible to improve oil moisture retention and promote natural regeneration.
5. Reconstruct floodplains and terraces that are topographically variable, to allow some depressions a longer period of saturated soil conditions.
6. Encourage channel migration at all sites where no human structures are at risk so the channel can construct a contemporary floodplain.
7. Target Fremont cottonwood and valley oak at riparian restoration projects to replace dying pre-NDPP generations.
8. Remove exotic plants wherever possible.
9. Encourage floodplain inundation during flood control releases to deposit fine sediment and saturate floodplain soils.
10. Increase flood flow magnitude and variability over different water years to create and maintain topographic diversity on bars and floodplains.
11. During springtime flood control releases in wetter water years, maintain dam ramping rates less than 8 cm/day to facilitate cottonwood seedling survival.
12. Improve management of riparian zones that would encourage natural regeneration (e.g., eliminate grazing, landscaping maintenance in parks, etc.).

4. RESTORING THE TUOLUMNE RIVER CORRIDOR

Developing a restoration vision shared by all stakeholders is one of the primary functions of this report. In practice, however, rehabilitating or restoring a river corridor has different meanings for different people, a situation that can lead to considerable dissention among stakeholders if no common vision is developed. A vision shared by stakeholders, on the other hand, reduces political distractions, facilitates restoration and monitoring funding decisions by identifying and prioritizing common goals.

The Tuolumne River is a heavily managed system. A successful restoration strategy must acknowledge that the river will never return to historical conditions in our lifetimes. However, reversing more than a century of environmental degradation and significantly improving the health of the river is essential. Developing specific restoration goals and a shared vision, appropriate strategies and approaches, then identifying potential restoration sites and priority projects, are the first steps toward restoring ecological health and integrity to the Tuolumne River. Implementation of the Restoration Plan and adaptive management by the TRTAC will measure restoration success.

4.1. RESTORATION GOALS AND OBJECTIVES

As discussed in Section 1.3.1, most past research on the Tuolumne River focused on biological habitat conditions, whereas fluvial and riparian processes are largely responsible for forming and maintaining biological habitat, and thus must be incorporated into a comprehensive restoration approach. In Chapter 2, we began our evaluation of fluvial and riparian processes by first developing the Attributes of Alluvial River Integrity, which serve as quantitative and qualitative restoration objectives. Then, in Chapter 3, we began quantifying many of these attributes by evaluating the evolution and dynamics of the M.J. Ruddy Four Pumps Restoration Project (Attribute 1), evaluating opportunities for improving flood peak variability (Attribute 2), measuring and modeling bed mobility (Attribute 3), measuring and modeling bedload transport rates (Attribute 5), identifying bedload impedance reaches, and gravel introduction sites and sources (Attribute 5), inventorying riparian vegetation from La Grange Dam to the San Joaquin River (Attribute 9), and documenting existing and remnant riparian stand associations with hydrology and channel morphology (Attributes 2, 7, and 9). These evaluations supplemented the large biological database that existed for the Tuolumne River to strengthen recommendations presented in the Restoration Plan. Again, while the Restoration Plan targets chinook salmon as a key management species, the restoration strategy is intended to improve conditions for a variety of plant and animal populations within the Tuolumne River corridor.

4.1.1. Goals and objectives of existing restoration programs

Several restoration plans and programs have been developed in the Central Valley, CA, over the last several years. The various goals and objectives of these programs were considered during development of the Tuolumne River Restoration Plan goals and objectives.

4.1.1.1. CDFG Restoring Central Valley Streams: A Plan For Action

The specific goals of the CDFG Plan, as presented in Governor Pete Wilson's April 1992 Water Policy Statement, are to restore and protect California's aquatic ecosystems that support fish and wildlife, and to protect threatened and endangered species. The goals of this plan also incorporate the State-legislated mandate and policy to double 1988 population levels of anadromous fish in California (Salmon, Steelhead Trout and Anadromous Fisheries Program Act, 1988). This equates to an adult escapement target of 12,600 chinook salmon on the Tuolumne River. The highest priority actions (A1) recommended for the Tuolumne River include: (1) restore spawning, rearing, and migration habitat, (2) require adequate streamflow releases for the protection of salmon spawning, rearing, and outmigration, (3) establish water quality objectives for the protection of spawning, rearing, and outmigration, (4) evaluate effects of fluctuating flows due to power peaking on salmon spawning and rearing, (5) evaluate fish screening needs, and (6) complete evaluation of spawning, rearing, and migration habitat restoration needs.

4.1.1.2. USFWS Anadromous Fish Restoration Program (AFRP)

The AFRP was developed by the US Fish and Wildlife Service in response to the 1992 Central Valley Project Improvement Act (CVPIA 1992), federal legislation that directed the Secretary of the Interior to develop and implement a program to restore anadromous fish populations to Central Valley streams. Specifically, the Secretary's mandate was:

> "develop within three years of enactment [of CVPIA] and implement a program which makes all reasonable efforts to ensure that, by the year 2002, natural production of anadromous fish in the Central Valley rivers and streams will be sustainable, on a long-term basis, at levels not less than twice the average levels attained during the period of 1967 to 1991…"

The fall-run chinook salmon population target set by the AFRP for the Tuolumne River is 38,000 returning adults. The program also established that first priority be given to measures which "protect and restore natural channel and riparian habitat values through habitat restoration actions" to ensure that both physical and biological ecosystem components can resist declines and recover from both natural and anthropogenic disturbances.

4.1.1.3. CALFED Ecosystem Restoration Program

The CALFED Ecosystem Restoration Program Plan (ERPP) was developed to address the CALFED goal for ecosystem quality, which is "to improve and increase aquatic and terrestrial habitats and improve ecological functions in the Bay-Delta to support sustainable populations of diverse and valuable plant and animal species." The program is explicitly founded on rehabilitation of ecological processes associated with streamflow, stream channels, floodplains and watersheds throughout the Central Valley as an essential requirement for sustaining resilient populations of fish and wildlife, and thus represents a significant shift in strategy from single-species management.

While one primary purpose of the CALFED Program is to ensure reliable water supplies for present and future consumptive uses, the FERC Settlement Agreement has precedence in determining minimum streamflow requirements in the Tuolumne River. Additionally, the FERC Settlement Agreement has provisions (Sec. 11 and 18) for supporting "Ancillary Programs" that include the transfer of water for instream environmental uses downstream of the dams.

4.1.2. New Don Pedro Project FERC Settlement Agreement

Article 37 of the New Don Pedro Project License (No. 2299-024), issued by the Federal Power Commission (later renamed the Federal Energy Regulatory Commission, FERC) in 1964, required reevaluating the project's minimum flow requirements after the first 20 years of operation (the NDDP was completed in 1971). FERC initiated this evaluation in 1994, and prepared a Final Environmental Impact Statement (FERC FEIS 1996) in compliance with the National Environmental Policy Act (NEPA). The FEIS evaluated a range of flow modifications and non-flow mitigation, which resulted in adoption of the FERC Settlement Agreement, entered into among the following Tuolumne River Stakeholder groups:

- California Department of Fish and Game (CDFG)

- California Sports Fishing Protection Alliance (CSPA)
- City and County of San Francisco (CCSF)
- Federal Energy Regulatory Commission (FERC)
- Friends of the Tuolumne (FOTT)
- Modesto Irrigation District (MID)
- San Francisco Bay Area Water Users Association (BAWUA)
- Tuolumne River Expeditions (TRE)
- Tuolumne River Preservation Trust (TRPT)
- Turlock Irrigation District (TID)
- U.S. Fish and Wildlife Service (USFWS)

Participants agreed to support the Settlement Agreement, which provided a revised instream flow schedule for NDPP operation (Table 2-5), and outlined a strategy for recovery of Tuolumne River chinook salmon (Articles 8-13). Restoration objectives listed in Sections 8-13 of the Settlement Agreement are:

- Increase naturally occurring salmon populations.
- Protect any remaining genetic distinction [among salmon populations].
- Increase salmon habitat in the Tuolumne River.
- Implement measures generally agreed upon as necessary to improve chinook salmon habitat and increase salmon populations. These measures include increased flows (FSA Flow Schedule), habitat rehabilitation and improvement, and measures to improve smolt survival.
- Implement additional measures of some risk that the Technical Advisory Committee (TAC) agrees may help improve the population.
- Use an adaptive management strategy that would initially employ measures considered feasible and have a high chance of success.
- [Conduct a detailed annual review] to assess progress toward meeting the goals described in the Settlement Agreement.

The Settlement Agreement stipulates that success of the flow modifications and non-flow mitigation measures will be re-evaluated again in 2005. This Restoration Plan represents the primary planning product of the Settlement Agreement, by cooperatively developing a restoration vision (how do we want the river corridor to function to best support chinook salmon and other native species), as well as identifying and prioritizing restoration projects. The restoration vision, shared by stakeholders, is an essential component of any restoration effort because it provides focused political and technical committment towards a common goal.

4.1.3. River-wide restoration goals

As illustrated in Chapter 2, salmonid life history strategies have adapted to the natural hydrologic and fluvial processes on the Tuolumne River, and to the habitat conditions and biological communities created and maintained by those processes. Accordingly, strategies for recovering and sustaining a robust chinook salmon population must be based on restoring fluvial processes to improve ecological health and integrity to the fullest extent possible, given contemporary sediment and flow regimes. Restoring ecosystem processes provides for the life-history requirements of salmon over the long term, as well as for other riverine species.

The Tuolumne River has the greatest restoration potential among the San Joaquin River tributaries for several reasons. First, periodic high flow releases for flood control operations can help restore fluvial geomorphic functions to the channel and alleviate riparian vegetation encroachment. A more variable streamflow schedule can also improve chinook salmon habitat and help restore several life history phases. Additionally, management institutions and stakeholder groups possess a broad ecological understanding of the Tuolumne River, and are committed to the goal of ecosystem restoration and salmon recovery. Finally, with the infusion of restoration funding for implementation, the Tuolumne River has the tools necessary to improve the river ecosystem, and sustain a robust, naturally producing salmon population.

The two biggest challenges facing restoration of the Tuolumne River are first, implementing a comprehensive Restoration Plan that includes short-term and long-term strategies for restoring and managing the river, and second, minimizing impacts of future development within the Lower Tuolumne River corridor. Both challenges are inextricably linked. The restoration effort must assess and work with future development within the river corridor, or restoration will continue to follow in an attempt to mediate ongoing development, at considerable public expense. The 1997 flood caused extensive damage to the river and surrounding infrastructures, but it also increased public awareness of the river, and illustrated the fundamental need for a wider floodway with larger flood capacity. Public interest in promoting aesthetic and recreational values on the river has also increased. These factors have given us the timely opportunity to implement a Restoration Plan that not only improves environmental conditions along the river, but can also provide benefits to public and private infrastructure, and other public rsources, as well.

Historical and contemporary impacts to the Tuolumne River have far exceeded the river's capacity for self-recovery in a timeframe acceptable to stakeholders. Therefore restoration will initially require a large degree of active, mechanical restoration, such as filling in-channel pits, introducing spawning gravel by re-creating in-channel alluvial deposits, and revegetating riparian zones. While acknowledging that the river cannot be restored to its pristine condition, this Restoration Plan recommends this initial "jump-starting," of active habitat restoration, followed by flow and sediment management that re-establishes natural processes at a scale corresponding to contemporary sediment and hydrologic regimes. Inherent with any restoration program of this large scale is some degree of uncertainty as to how effective, and within what time-frame, restoration will be in contributing toward chinook salmon recovery. Therefore, adaptive management must closely monitor and refine restoration approaches to ensure successful recovery of natural chinook salmon production.

The physical and biological attributes that define a healthy alluvial river change with longitudinal distance as the Tuolumne River emerges from the mountains and foothills of the Sierra Nevada Range and meanders through the Central Valley. For example, river behavior in a sand-bedded river can be different than a gravel-bedded river. These attributes underpin the structure and function of the river ecosystem and determine local and reach-wide variation in river morphology. As described in Chapter 2, the lower Tuolumne River has two geomorphically distinct units (Figure 4-1): a moderate gradient, gravel-bedded zone from La Grange Dam (RM 52.2) downstream to below Fox Grove County Park (RM 24), and a low gradient sand-bedded zone extending to the confluence with the San Joaquin River (RM 0). These two zones are divided into 7 reaches characterized by general restoration needs that resulted from current and historic land use practices.

River-wide restoration goals for the Tuolumne River include:

- A continuous river floodway from La Grange Dam to the confluence with the San Joaquin River with capacity that safely conveys at least 15,000 cfs above Dry Creek and 20,000 cfs below Dry Creek;
- A continuous riparian corridor from La Grange Dam to the San Joaquin River confluence, with a width exceeding 500 ft minimum in the gravel-bedded zone to a width up to 2,000 ft near the San Joaquin River;
- A dynamic alluvial channel, maintained by flood hydrographs of variable magnitude and frequency adequate to periodically initiate fluvial geomorphic processes (e.g., mobilize channelbed surface, scour and replenish gravel bars, inundate floodplains, and promote channel migration);
- Variable streamflows, such as during chinook spawning, rearing and emigration, to benefit salmon and other aquatic resources;
- A secure gravel supply to replace gravel transported by the high flow regime, thus maintaining the quantity and quality of alluvial deposits that provide chinook salmon habitat;
- Bedload transport continuity throughout all reaches;
- Chinook salmon habitat created and maintained by natural processes, sustaining a resilient, naturally reproducing chinook salmon population;
- Self-sustaining, dynamic, native woody riparian vegetation;
- Continual revision of the adaptive management program, addressing areas of scientific uncertainty that will improve our understanding of river ecosystem processes and refine future restoration and management;
- Public awareness and involvement in the Tuolumne River restoration effort;
- A clean river. Our perception of a river's intrinsic value is largely based on visual aesthetics. To most people, a clean river is worth caring for, and the public will be more conscious of keeping it clean.

These restoration goals apply to all geomorphic reaches defined in Chapter 2. Because of land use differences among the seven different reaches, primary restoration issues differ between reaches. The following section presents specific restoration strategies for each reach (Figure 4-1) that target these primary restoration issues.

4.2 RESTORATION STRATEGIES

4.2.1. Sand-Bedded Zone (San Joaquin River RM 0 to Fox Grove Park RM 24)

Primary restoration issues: Agricultural and urban encroachment of floodway, rip-rap levees, loss of riparian vegetation, loss of off-channel wetlands, loss of channel migration, poor water quality, refuse.

Overall restoration strategies for all sand-bedded reaches:

- Improve salmon rearing capability by improving water quality through urban and agricultural runoff management programs, and by improving water temperatures during rearing and outmigration periods;
- Restore floodway capacity to 15,000 cfs or greater above Dry Creek, and 20,000 cfs or greater below Dry Creek;
- Reduce permanent urban and agricultural encroachment to create/maintain a 500-2,000 ft or greater floodway width;
- Remove rip-rap and levees where feasible to restore a functional floodplain and natural channel migration within the floodway;
- Improve water quality in Dry Creek;
- Restore a continuous corridor of native riparian hardwoods;
- Seek voluntary conservation easements and/or land acquisitions (especially of flood-prone lands) to increase riparian corridor width;
- Remove exotic plants within riparian corridor.
- Protect remaining mature valley oaks and Fremont cottonwoods.

4.2.2. Gravel-Bedded Zone (Fox Grove RM 24 to La Grange Dam RM 52.1)

Primary restoration issues: Agricultural encroachment in floodway, historical instream and present-day off-channel gravel mining, rip-rap bank protection, dikes, dredger tailings, livestock grazing, fine sediment accumulation, spawning gravel supply, moderate to poor salmon spawning and rearing habitat quality, riparian encroachment along the low flow channel.

Overall restoration strategies for all gravel-bedded reaches:

- Increase coarse sediment supply and maintain coarse sediment budget;
- Reduce fine sediment supply.
- Restore floodway capacity to 15,000 cfs or greater;
- Reduce agricultural and mining encroachment to create/maintain a 500 ft or greater floodway width;
- Remove rip-rap and levees where appropriate to restore a functional floodplain and allow natural channel migration within the floodway;
- Manage flood control releases to increase frequency of floods that exceed fluvial geomorphic thresholds (e.g., bed surface mobilization);
- Provide variability in streamflows to increase heterogeneity of physical habitat;
- Restore a continuous corridor of native riparian hardwoods;
- Revegetate restored floodplains and terraces with native riparian plant assemblages;
- Improve habitat quality of off-channel wetlands;
- Seek voluntary conservation easements and/or land acquisitions (especially of flood-prone lands) to increase riparian corridor width;
- Remove exotic plants from within the riparian corridor;
- Develop alternative grazing strategies to increase natural riparian regeneration;
- Protect existing mature valley oaks and Fremont cottonwoods.

SAND-BEDDED ZONE (RM 0.0 to RM 24.0)

- Restore floodway capacity to 15,000 cfs or greater above Dry Creek and 20,000 cfs or greater below Dry Creek
- Reduce urban and agricultural encroachment to create/maintain a 500-2,000 ft or greater floodway width
- Remove rip-rap and berms where feasible to restore floodplains and to allow migration within the floodway
- Seek conservation easements and/or land acquisitions (especially of flood-prone lands) from willing landowners

REACH 1 (RM 0.0-10.5)
Lower Sand-bedded Reach

- Restore off-channel wetlands to increase wildlife habitat
- Create vegetative buffer to reduce soil erosion and filter agricultural runoff
- Restore functional floodplains and native riparian forests

REACH 2
(RM 10.5-19.3)
Urban Sand-bedded Reach

- Increase public awareness of the Tuolumne and promote cleanup, restoration and monitoring
- Improve Tuolumne River Regional Park by increasing area of native riparian trees
- Create and preserve riparian buffer along urban/industrial zones
- Remove trash and debris, eliminate chronic sources of pollution, and actively monitor illegal dumping

REACH 3
(RM 19.3-24.0)
Upper Sand-bedded Reach

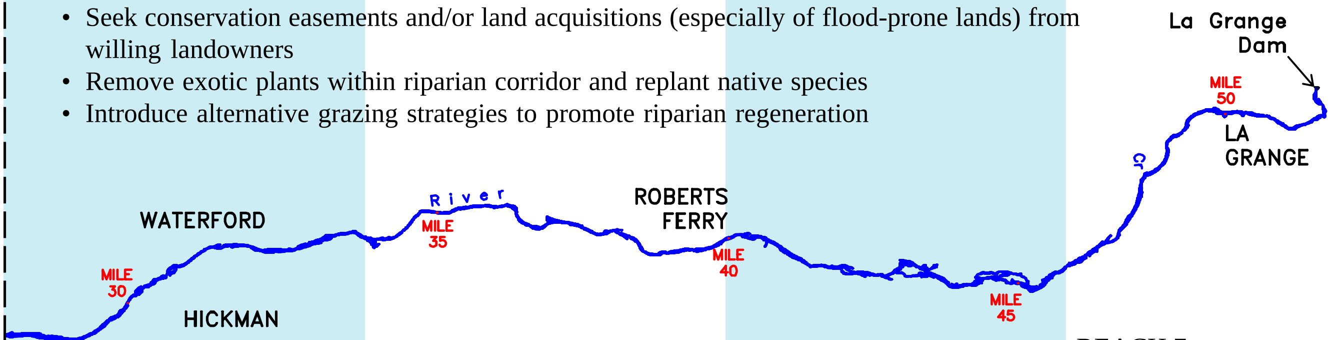
- Preserve existing urban setback from river
- Create and preserve a riparian buffer along urban/agricultural zones

REACH 4
continued

Figure 4-1. Geomorphic reach delineation and proposed restoration strategies for the lower Tuolumne River.

GRAVEL-BEDDED ZONE (RM 24.0-52.1)

- Increase gravel supply throughout the zone and increase the frequency of gravel movement
- Reduce fine sediment supply and storage
- Restore floodway capacity to 15,000 cfs or greater
- Reduce agricultural and mining encroachment to create/maintain a 500 ft or greater coridor width
- Remove rip-rap and berms where feasible to restore floodplains and to allow migration within the floodway
- Manage flood control releases to initiate bed movement and other dynamic channel processes
- Restore a continuous corridor of native riparian vegetation
- Improve habitat quality of off-channel wetlands
- Seek conservation easements and/or land acquisitions (especially of flood-prone lands) from willing landowners
- Remove exotic plants within riparian corridor and replant native species
- Introduce alternative grazing strategies to promote riparian regeneration



REACH 4
(RM 24.0-34.2)
In-Channel Gravel Mining Reach

- Isolate/fill instream mining pits to reduce bass predation on juvenile salmon and reestablish bedload transport continuity
- Restore a natural river and floodplain
- Create and maintain riparian buffer (corridor) along urban/agricultural zones

REACH 5
(RM 34.2-40.3)
Gravel Mining Reach

- Isolate off-channel mining pits to prevent river connection during floods up to 15,000 cfs to reduce salmon stranding and bass predation on juvenile salmon
- Increase floodway width to at least 500 feet
- Restore a natural river and floodplain morphology
- Restore and maintain riparian corridor through gravel mining zones

REACH 6
(RM 40.3-46.6)
Dredger Tailing Reach

- Reconstruct remnant channel left by gold dredger operations to a natural river and floodplain form
- Restore riffles to increase salmon spawning and rearing habitat
- Regrade floodplains to reduce salmon stranding and promote riparian regeneration
- Reduce riparian encroachment onto low flow channel
- Reduce grazing impacts to promote riparian regeneration
- Secure remnant dredger tailings for future restoration

REACH 7
(RM 46.6-52.1)
Dominant Spawning Reach

- Reduce sand input into river and storage in riverbed (especially in spawning gravels)
- Increase and maintain spawning gravel supply
- Restore riffles to increase salmon spawning and rearing habitat
- Regrade floodplains to reduce salmon stranding and promote riparian regeneration
- Reduce riparian encroachment onto active channel
- Reduce grazing impacts to promote riparian regeneration on floodplains

4.3. RESTORATION AND PRESERVATION APPROACHES

Specific approaches to achieve the above restoration visions are discussed below.

4.3.1. Preservation sites

Preserving the integrity of a site where human influence has been minimal and ecological conditions have remained healthy should be prioritized equally with restoration sites. Preserving reaches that are functioning well today is much cheaper than restoring them tomorrow. Potential preservation sites can be moderately disturbed but must be easily restorable. High priority preservation sites should have:

(1) high quality chinook salmon habitat, and/or
(2) stands of Fremont cottonwood and valley oak, and/or
(3) a migrating channel creating diverse habitat (which is rare on the Tuolumne River).

The highest priority site in the first category is the Dominant Spawning Reach (Reach 7 in Figure 4-1) from Old La Grange Bridge (RM 50.5) downstream to the New Basso Bridge (RM 47.6). This reach is often heavily grazed, with livestock often walking through spawning riffles during and after spawning. The dredger tailings have been removed, leaving an unconfined floodplain surface that offers considerable potential for riparian revegetation and channel migration. The second priority site is the Dredger Tailing Reach (Reach 6 in Figure 4-1), which also has important spawning habitat, sometimes heavy grazing, and few remaining dredger tailings. The Dredger Tailing Reach, with large stands of mature cottonwoods and a wide floodway, has the best potential for riparian forest restoration in the entire gravel-bedded reach. However, damage to the channel by gold dredging must be remedied before expecting significant improvement in salmon spawning and rearing habitat.

Reaches on the Tuolumne River where the channel is migrating, creating alternate bars, and constructing contemporary floodplains are rare in the gravel-bedded zone, but less so in the sand-bedded zone. Their rarity in the gravel-bedded zone and their importance to salmon habitat requires that these sites in the gravel-bedded zone receive higher priority. Two examples are: (1) immediately upstream of the Roberts Ferry Bridge, where the channel is migrating into dredger tailings (RM 40.3), and (2) at RM 34.3 where the channel is migrating into an old floodplain on the south bank. Bank erosion is supplying gravel and cobbles to the river channel; dynamic bars are forming immediately downstream, providing high-quality salmon habitat. Wherever possible, sites with a migrating channel should be preserved, preferably with a purchase or easement.

4.3.2. Floodway expansion

As illustrated by the January 1997 flood (see Section 3.1.6), adequate floodway capacity and functional floodplains are crucial to a healthy river corridor. Many reaches have thin topsoil or gravel dikes that confine the river between deep pits, particularly in aggregate extraction areas. In several areas the entire floodway width is as narrow as 125 feet. Dikes are particularly prone to failure at moderate flood flows as low as 8,000 cfs. When dikes fail, the river “captures” the entire floodplain gravel pit, and the pit remains connected to the main channel. Additionally, confinement by the dikes does not allow stream energy to naturally dissipate on floodplains and riparian vegetation, but instead redirects the river’s energy against the bed surface, degrading the channel. Highly confined reaches (e.g., downstream of Basso Bridge due to riparian encroachment, and within the Gravel Mining Reach due to confining dikes) have become long, deep pools, with few, if any, riffles or other instream alluvial deposits. Alluvial deposits have been scoured away over time, as shown in Figures 3-21 and 3-22.

The ecologically and hydraulically preferable solution is to increase the floodway width by either moving dikes back from the channel (Figure 4-2) or by selectively removing riparian, agricultural, or dredger tailing confinement (Figure 4-3). Floodplains reconstructed to convey high flows from 4,500 up to 15,000 cfs upstream of Dry Creek (RM 16.4), and up to 20,000 cfs downstream of Dry Creek, will greatly improve floodway capacity and NDPP operational flexibility, thus greatly reducing the risk of future catastrophic floods. Restoring floodplains and a meandering channel will increase energy dissipation by creating bar features and encouraging riparian vegetation, rather than downcutting the channelbed and eroding dikes (Figure 4-4).

Floodway width of at least 500 ft in the gravel-bedded zone is recommended for the following reasons:

- In reaches with minor or no channel damage during the January 1997 flood, the minimum floodway width was 500 ft.
- Most bridge crossings and hard infrastructure constraints can be avoided by a 500 ft wide floodway.
- A 500 ft wide floodway will increase floodplain storage of high flows, helping attenuate short duration peak flows.
- A riparian corridor can have several mature cottonwoods or valley oaks on each side of a 200 ft wide bankfull channel, capable of creating a continuous corridor on both sides of the river with a closed canopy and associated terrestrial habitat.
- A 500 ft wide floodway provides room for the channel to migrate in the future (migrate through a floodplain or terrace rather than through dikes).

A 500 ft wide floodway also conveys a maximum desired flood control release of 15,000 cfs. The NDPP outlet works capacity is 14,500 cfs, and added to 500 cfs of downstream flow accretion during a storm event, results in a desired floodway capacity of 15,000 cfs upstream of Dry Creek. Flow capacity was computed in a 500 ft wide channel (Figure 4-5), using the following assumptions:

1. Energy slope = 0.0015 based on 5400 cfs water surface slope measured at many locations in the gravel-bedded zone in the spring of 1996;
2. Manning's $n = 0.028$ over entire channel immediately after construction (smoothest channel conditions) based on HEC-RAS back-calculations of the 5,400 cfs flow measured in the spring of 1996;
3. Manning's $n = 0.035$ within the bankfull channel and $n = 0.075$ on floodplain/terrace surfaces after vegetation has established and begun to mature (roughest channel conditions);
4. At least 3 feet of freeboard above water surface required for dike stability.

Results suggest that a 20,000 cfs flood could be conveyed with 6 feet of freeboard immediately after construction, and 4 to 5 feet of freeboard after riparian vegetation establishment roughened the channel (Figure 4-5). The 20,000 cfs value was used as a conservative discharge. Both roughness scenarios pass the "safe" test with the same safety factor (2 to 3 feet). For the rougher channel condition, average channel velocities were 5.5 to 6.0 ft/sec, floodplain velocities were approximately 2 ft/sec, and main channel velocities were 7.5 to 8.0 ft/sec. This simple calculation, however, does not account for reaches with lower slope, non-uniform flow, and increased roughness from bars and channel curvature. Each channel restoration project should evaluate floodway width needs using an appropriate hydraulic model (e.g., HEC-RAS).

4.3.3. Riparian restoration strategies

Riparian revegetation must be compatible with restored hydrologic and fluvial processes. As shown in Chapter 3, riparian plant species have adapted to specific geomorphic surfaces that are inundated by specific flood recurrence intervals. General riparian restoration strategies should target Fremont cottonwood and valley oak as the highest priority species due to their historic role as dominant canopy structure and their subsequent demise over time. Riparian restoration strategies include:

- plant cottonwoods on floodplain surfaces;
- plant valley oaks on floodplain and terrace surfaces;
- integrate revegetation with channel restoration wherever possible (e.g., use narrow-leaf willow bioengineering on outsides of meanders where constraints prohibit migration);
- construct topographic depressions on floodplain surfaces to create moist seedbeds that will encourage natural riparian regeneration;
- revegetate restored floodplains and terraces in the gravel-bedded zones in patches rather than rigid grid spacing, preferably following constructed topographical depressions (see Figures 2-19 and 2-38). This mimics the natural patchiness of historic riparian forests in the gravel-bedded zone, creating interior habitat for wildlife, creating perching and roosting canopy structure, and providing a closed canopy;

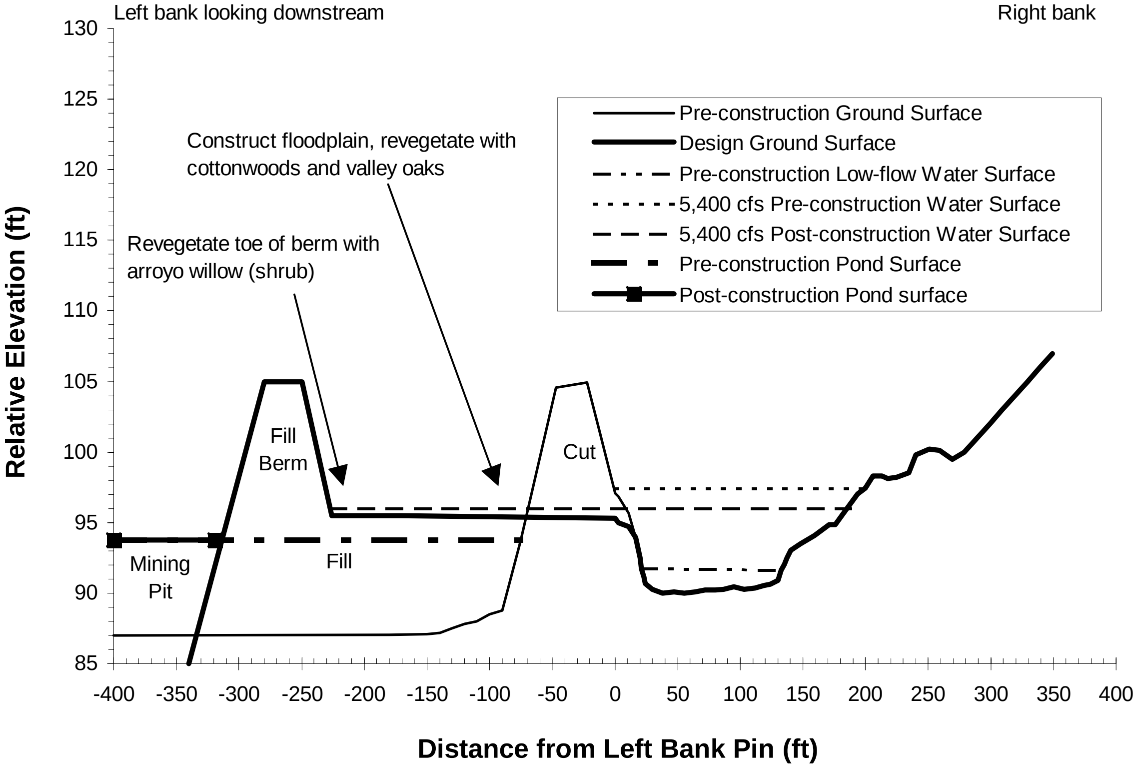


Figure 4-2. Proposed modification to berm confined channel morphology to improve flood conveyance and reduce habitat damage during large floods.

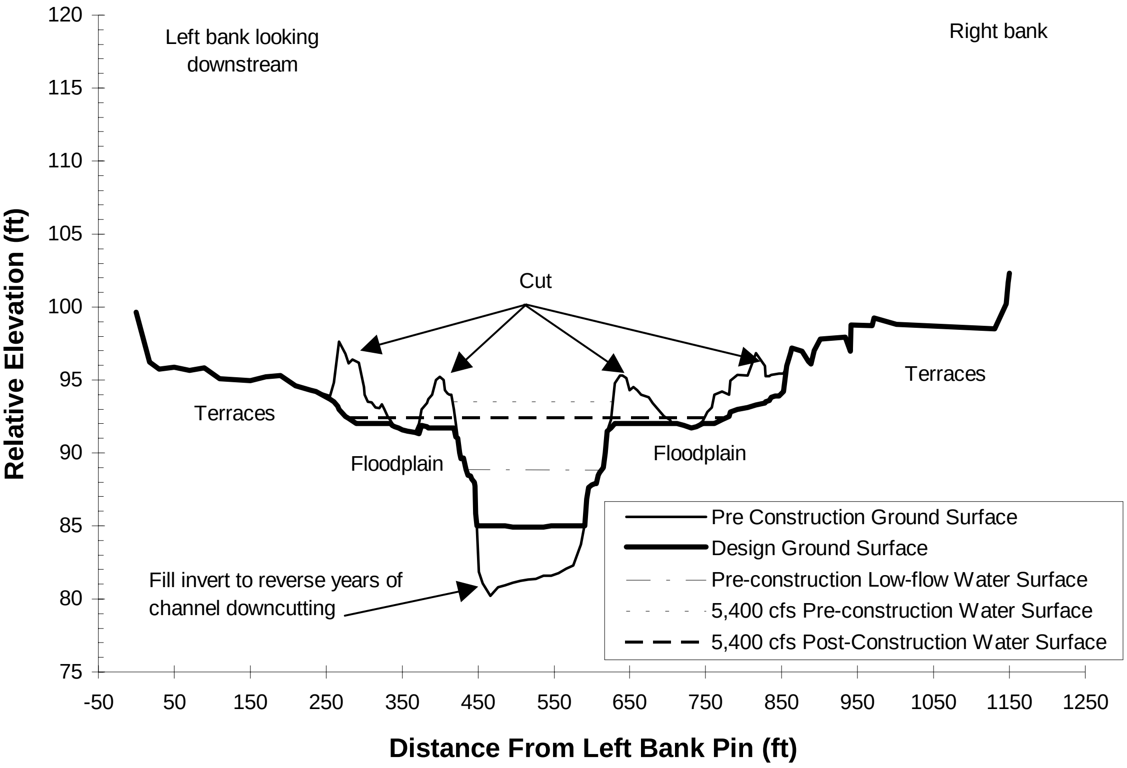


Figure 4-3. Proposed modification to riparian and/or agriculturally encroached channel morphology to improve flood conveyance and reduce habitat damage during large floods.

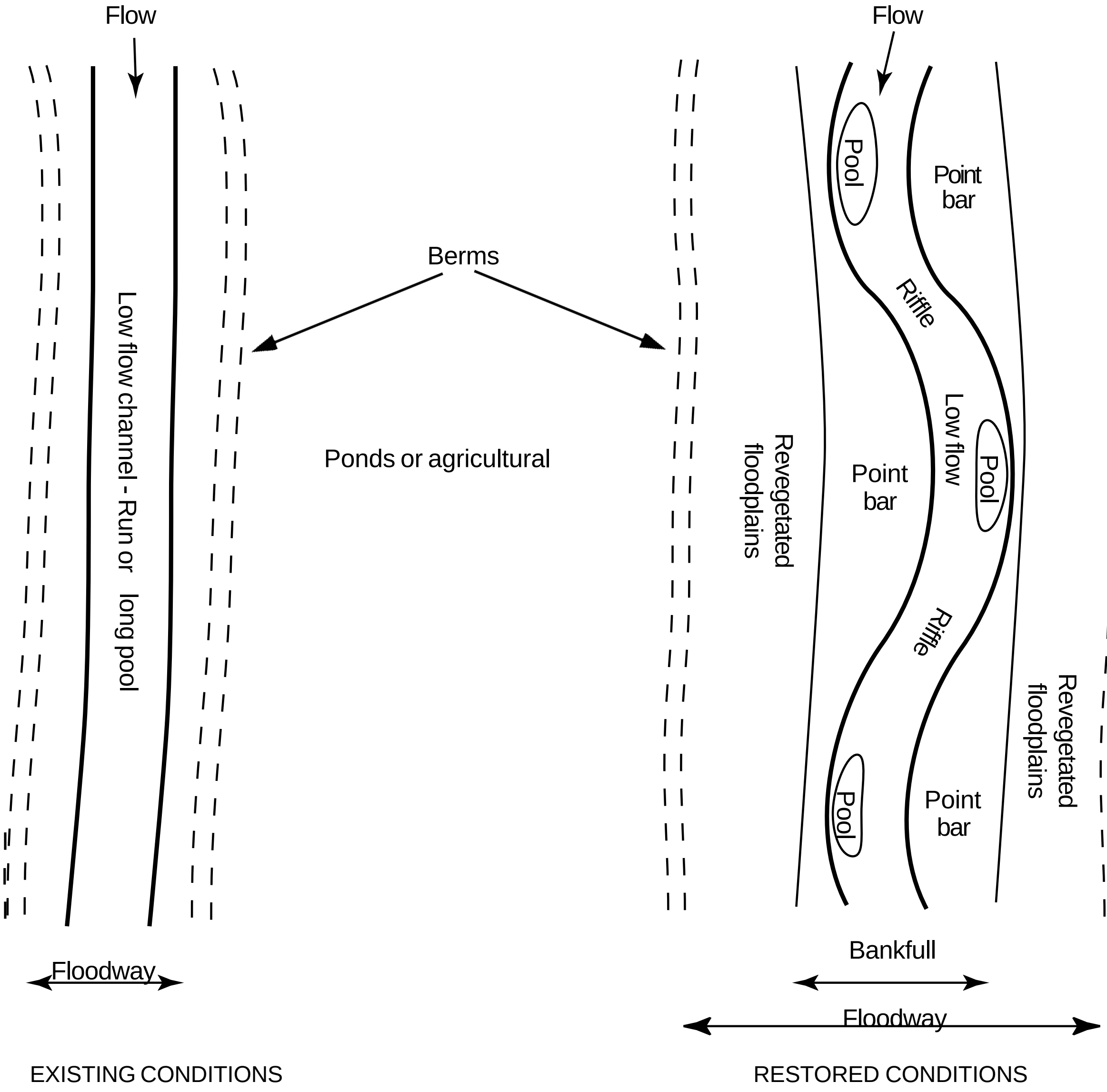


Figure 4-4. Recommended restoration strategy for straight reaches, converting incised channel to natural alternate bar sequence with two stage channel. Note: Alternate bar morphology is idealized; designed conditions should be more variable. Suggested dimensions are listed in Section 4.3.4 of the report.

- revegetate restored floodplains and terraces in the sand-bedded zone completely (as opposed to patches) using conventional farming techniques. Vegetation should be planted in staggered rows or in pseudo-sine waves, mimicking the natural spatial variability and achieving complete vegetation coverage. Complete planting coverage will become dense gallery forests (much like Figure 2-17 and 2-27) and will provide interior forest habitat essential to wildlife (e.g., yellow billed cuckoo);
- revegetate by series rather than species to provide both the canopy species and understory species;
- actively remove confining riparian berms as part of restoration projects in areas where vegetative encroachment has occurred into the active channel;
- protect all restoration and preservation sites from future disturbance through conservation easements or land purchases.

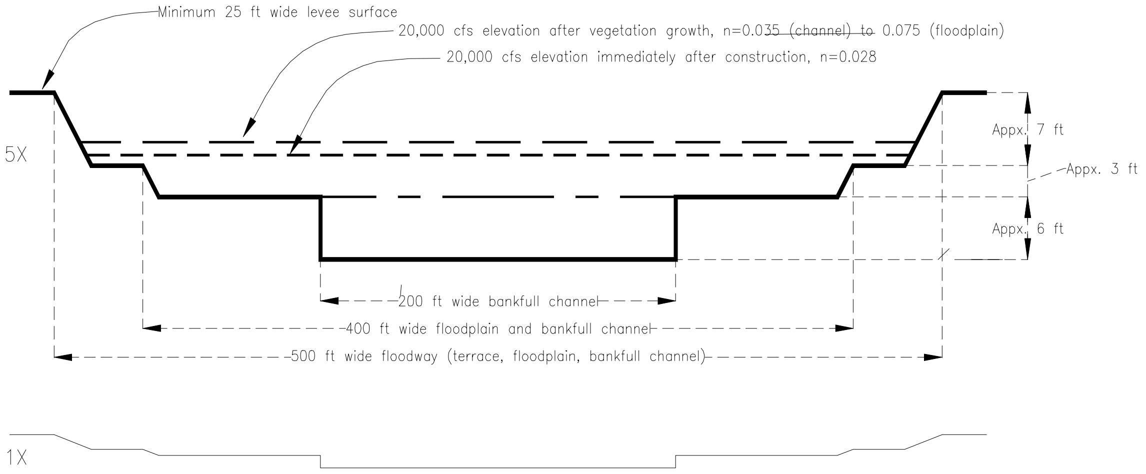


Figure 4-5. Conceptual restored floodway, with bankfull channel, floodplain, and terraces.

4.3.4. Channel reconstruction

Channel reconstruction must incorporate dynamic fluvial geomorphic processes and a variable hydrologic regime in the design. Bed mobilization and channel migration should be accommodated and encouraged. Floodplains should be constructed to encourage fine sediment deposition on their surfaces. Designing channel restoration projects within this dynamic framework will allow the river channel to naturally form and maintain diverse habitat. A migrating channel with an alternate bar morphology increases topographic complexity. The ensuing hydraulic complexity generates a complex channelbed (Attribute #1) exhibiting a diverse particle size distribution. All physical adjustments combine to sustain complex habitat for many species. Moderate channel self-adjustment, therefore, should be considered a key characteristic for a successful restoration project.

As discussed above, the minimum floodway width should be no less than 500 ft, and considerably wider as valley confinement ends downstream of Modesto. This channel design consideration depends on the high flow regime. A larger floodway width is needed downstream of Dry Creek to accommodate larger flood control releases and tributary accretion. The floodway serves environmental benefits along the Tuolumne River corridor (riparian and channel restoration) as well as improves operational flexibility of the NDPP flood management system.

Primary channel design parameters, including bankfull channel width, depth, meander wavelength, radius of curvature, and sinuosity (dependent variables), are tailored to more common “channel maintaining” floods, channel slope, and particle size (independent variables). All these variables have some degree of interdependence, and at times, can all be unknown. The first step is to fix the primary independent variable: the channel maintaining flow. We use bankfull discharge as a surrogate for the channel maintaining flow, which is a primary variable for determining channel dimensions. Bankfull discharge is typically within the 1.5 to 2.5 year flood recurrence, and has decreased over the years with each new dam on the Tuolumne River. Using the post-NDPP high flow regime, the 1.5 and 2.5 year floods are 2,600 cfs and 4,400 cfs, respectively. The maximum release from which NDPP can generate power is approximately 5,500 cfs. Many past floods have peaked between 5,000 cfs and 5,500 cfs. If flood control modifications are implemented as recommended in Section 3.2.2, the 1.5 and 2.5 year flood would only increase to 2,700 and 5,000 cfs, respectively. The congruity of 5,000 cfs dam releases with bed mobility observations at the M.J. Ruddy restoration site indicates that a target future bankfull discharge be approximately 5,000 cfs.

Observations at the M.J. Ruddy 4-Pumps restoration project, measurements at model reaches, and regional relationships of bankfull discharge to channel dimension, resulted in the following channel design guidelines for restoratiion projects in the gravel bedded reach:

channel width at low water (~150 cfs)	75 - 90 feet
thalweg depth at low water (pools)	4 - 8 feet
thalweg depth at low water (riffles)	0.5 - 1.5 feet
width at spawning flow (300-500 cfs)	90 - 110 feet
average thalweg depth at spawning flow (riffles)	1 - 2 feet
average water velocity at spawning flow	1.3 - 2.5 feet/sec
bankfull discharge	5,000 cfs
bankfull width	175-200 feet
average bankfull depth	6 feet
average bankfull water velocity	4 - 5 feet/sec
max floodway width, including floodplains & terraces	>500 feet
maximum design floodway discharge	15,000 to 20,000 cfs
meander wavelength	1,600 - 2,000 feet
sinuosity	1.1 - 1.2
radius of curvature	large
high flow energy slope	0.001 to 0.002

These criteria were developed for the gravel bedded zone where bankfull slopes are between 0.001 and 0.002. Further consideration would be needed to develop similar design criteria for the sand-bedded zone, but channel reconstruction in the sand-bedded zone should be minimal, other than for reshaping floodplains for riparian restoration projects. The flood frequency distribution is also different below Dry Creek due to cumulative unregulated storm runoff from tributaries.

4.3.5. Fine sediment (sand) management

The objective of fine sediment management is to reduce fine sediment storage within the bankfull channel. To reduce fine sediment storage, each variable in the sediment budget equation “Input – Output = DStorage” must be targeted, including:

- Reduce Input. Construct sedimentation ponds in tributaries that deliver fine sediment to the Tuolumne River; improve land use practices within the corridor to reduce soil erosion and delivery to the Tuolumne River.
- Increase Output. Increase the magnitude and frequency of high flows to deposit fine sediment onto the floodplain; increase the magnitude, frequency and duration of high flows to scour, mobilize, and transport fine sediment downstream from primary spawning and rearing reaches.
- Mechanically reduce Storage. If above two methods do not sufficently reduce instream storage, excavate sand stored in pools, excavate sand from riparian berms and backwaters, excavate sand on Basso area floodplains that has high risk of returning to the river, and evaluate techniques to mechanically flush and remove sand from riffles. If fine sediment input is sufficiently reduced, mechanical removal would soon no longer be needed.

4.3.6. Coarse sediment (spawning gravel) management

A discussed in Chapter 2, dams on the Tuolumne River have trapped all coarse sediment derived from the upper watershed, preventing downstream reaches from being replenished. High flow events and instream aggregate extraction have progressively reduced coarse sediment supply within the bankfull channel. Coarse sediment includes gravels and cobbles which form high quality salmon habitat. The objective of coarse sediment management is to first reverse historic losses with a “transfusion,” of large volumes of coarse sediment, then maintain coarse sediment storage by periodically adding coarse sediment at a rate equal to the volume transported downstream by high flows. Coarse sediment introduction should first target the dominant spawning reach between La Grange Dam (RM 52.2) and Basso Bridge (RM 47.6) so that coarse sediment can then be routed downstream over time. Introducing coarse sediment as instream point bars and pool tails restores and replenishes habitat for immediate use by salmon (Figure 4-6). Later introductions should also occur downstream of the dominant spawning reach, particularly after restoration of bedload impedance reaches and the Gravel Mining Reach. Introduced coarse sediment should consist of gravel and cobble size classes only, from approximately 8 mm (1/4 in) diameter to 128 mm (6 in) diameter. These size classes are most useful to salmon, and are small enough to be mobilized by the contemporary high flow regime.

Coarse sediment is also naturally recruited from channel migration (bank erosion), so channel migration should be allowed to occur wherever possible. However, as channels migrate, there needs to be coarse sediment replenishment from upstream sources to rebuild point bars on the inside of bends. Channel migration does not necessarily provide a net input of coarse sediment when it occurs, but is a mechanism for sediment storage and routing. Maintaining coarse sediment supply in upstream reaches of the Tuolumne River is therefore necessary. Tributary contributions of coarse sediment is also negligible. The next priority is then filling bedload impedance reaches (see Section 3.1.1) that trap coarse sediments in transport. Restoring these reaches to a morphology properly sized to the contemporary high flow regime will allow coarse sediment from upstream sources to continue the deposition-mobilization-redeposition process that “recycles” introduced gravel year after year. Several conceptual restoration designs developed by the Restoration Plan target these impedance reaches.

4.3.7. Microhabitat restoration

Microhabitat restoration on a river the size of the Tuolumne River is typically a short-term strategy at best, because periodic high flows still occur with the capacity to destroy the restoration effort. Typical microhabitat restoration includes replacing substrate in riffles with clean gravel, constructing boulder weir grade control structures, placing boulder clusters for instream habitat, and mechanical gravel flushing. Most microhabitat restoration projects have had limited success (e.g., Kondolf et al. 1996), and should only be implemented if project benefits outweigh the costs of a short project life-span.

Mechanical gravel flushing may be a feasible short-term strategy for reducing fine sediment in

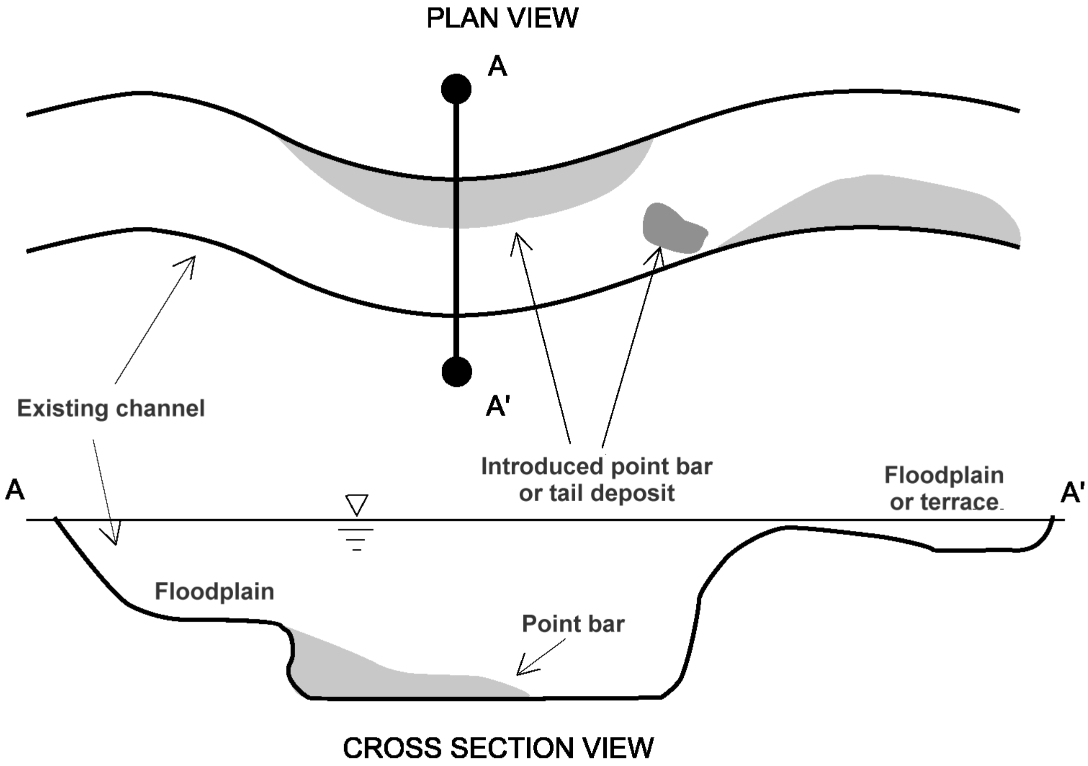


Figure 4-6. Suggested “gravel transfusion” insertion method to quickly restore and replenish instream alluvial deposits.

spawning gravels, and if implemented, should initially target the dominant spawning reach upstream of Riffle 5B (RM 47.9) under the following conditions:

- A solution to reduce fine sediment input from Gasburg Creek is implemented;
- Sand deposited on floodplain surfaces from the 1997 flood is removed and/or used to fill dredger pits on floodplains.

The longevity of the flushing effort must be increased by removing upstream sand sources to make mechanical sand flushing cost-effective. Sand sources downstream of Riffle 5B (e.g., Lower Dominici Creek and Peaslee Creek) will be more difficult to control; rapid sand infiltration will most likely shorten mechanical flushing effectiveness.

4.3.8 Miscellaneous

The TRTAC should consider identifying an appropriate site and installing an adult salmon counting station. While not specifically a restoration activity, a counting station would provide more accurate escapement estimates, and provide valuable information on migration timing. These counts could also augment/validate the spawning survey data collected by CDFG in the spawning reaches. Finally, a fish trapping station could be used to capture hatchery fish or out-of-basin strays and remove them from the Tuolumne River breeding population, thus protecting the genetic distinction of the Tuolumne River salmon, as mandated by the Settlement Agreement.

4.4. RESTORATION SITE IDENTIFICATION AND SELECTION

Many of the restoration projects identified by this plan are of much larger scale than has recently occurred, with project boundaries spanning the entire corridor width over several miles of channel length. We identified projects through a combination of discussions with local stakeholders and scientists, restoration site lists developed by others (EA Engineering, DWR, CDFG), and an extensive re-evaluation during numerous float trips and site visits. Restoration sites were either classified as a channel restoration project or riparian restoration project; however, most channel restoration projects contained a strong riparian component, whereas riparian projects were solely riparian.

The logical progression from identifying restoration projects to implementing restoration projects requires some prioritization to ensure that the most important projects are implemented first. Factors that limit salmon productivity and the fundamental fluvial processes that make the system function properly should logically be addressed first, then factors that are less imperative, and so on.

The task of prioritizing and selecting projects for implementation is beyond the scope of this document, but is the ultimate responsibility of the Tuolumne River Technical Advisory Committee. Priorities may be adjusted over time as projects are implemented and monitoring data can be used adaptively to re-evaluate project success and environmental responses to restoration actions. The criteria for selecting projects may also vary depending on the availability of funding and the type of funding source, opportunity (e.g., willing landowner), the types of projects that were implemented previously, and other unforeseeable circumstances. For example, several large-scale channel reconstruction projects have already received funding, and project implementation will begin in 2000. The TRTAC may choose to evaluate the performance of these relatively expensive projects before proceeding with additional channel reconstruction projects. Also, many of the riparian restoration projects depend on land purchases or conservation easements, both circumstances of which require willing landowners before these projects can proceed. The logical way to proceed, therefore, is for the TRTAC to remain opportunistic in the face of shifting availability of funding or land availability. In the interim, funding proposals were developed for fourteen channel restoration projects tentatively identified as high priority. These proposals are immediately available should the appropriate implementation opportunity arise.

Conceptual designs were developed for the following restoration projects, and summaries of the project background, objectives, project descriptions, and estimated costs are provided below:

1. Special Run Pool 5 (RM 32.9 to 33.4)
2. Special Run Pool 6 (RM 30.2 to 30.9)
3. Special Run Pool 9 (RM 25.6 to 25.9)
4. Special Run Pool 10 (RM 25.2 to 25.6)
5. Gravel Mining Reach Phase I (RM 37.7 to 40.3)
6. Gravel Mining Reach Phase II (RM 36.6 to 37.7)
7. Gravel Mining Reach Phase III (RM 35.2 to 36.6)
8. Gravel Mining Reach Phase IV (RM 34.3 to 35.2)
9. Sediment Management and Implementation Plan
10. Gasburg Creek Sedimentation Basin (RM 50.4)
11. Dredger Tailing Reach Phase I (RM 45.4 to 46.5)
12. Dredger Tailing Reach Phase II (RM 43.8 to 45.4)
13. Dredger Tailing Reach Phase III (RM 42.2 to 43.8)
14. Basso Spawning Reach Floodplain Restoration (RM 47.6 to 50.5)

Several projects that were not included in the list of 14 channel restoration projects deserve additional discussion. First, the bedload impedance reach between Riffle 5B (RM 47.9) and the late Riffle 6 (RM 47.0) presently prevents sediment transport through it, and will continue to do so in the future. Gravel introduced as part of the sediment management program will become deposited here and not route downstream to replenish the dredger tailing reach until this bedload impedance reach is fixed. Channel restoration and/or gravel additions in the dredger tailing reach will restore a large source of gravel for downstream movement, but over the long-term will be depleted until this impedance reach is filled. Any property in the dredger tailing reach that becomes available for fee title purchase or conservation easement should be pursued. This reach has substantial salmon and riparian production presently, and there is considerable potential to improve conditions in this reach. River front properties and those containing gravel sources should be prioritized for preservation and restoration or material sources, respectively.

The remaining two projects are SRP 7 (RM 26.0 to 27.8) and SRP 8 (RM 27.9 to 29.5), which are extremely large remnant instream aggregate extraction pits. The cost to restore these pits is large (over $5 million each). Restoration of two similar sites (SRP 9 and 10) are underway, and we recommend that their effectiveness be evaluated before proceeding with additional pit filling projects in the future to determine their cost-effectiveness. These three projects should be further developed in the near future within an expanded list of projects.

An additional three projects that are currently being developed also warrant discussion. The “Grayson River Ranch Project” is a 140 acre floodplain parcel on the south bank of the Tuolumne River between river miles 5 and 6. The property owners applied for and received a “perpetual conservation easement” for their property in response to the 1997 flood and frequent past flooding. The USDA Natural Resources Conservation Service administers easement agreements in cooperation with the East Stanislaus County Resource Conservation District, linking with various local, state, federal, and non-profit partners for funding and restoration coordination.

In the upper river, the “Bobcat Flat Project” involves the potential acquisition of a 280 acre parcel. The project involves the fee acquisition of a large floodplain with two miles of river frontage in the dredger tailing reach. It has significant potential for enhanced natural floodplain function. The proposal was submitted by the Friends of the Tuolumne, and funding for the purchase and restoration has been approved by CALFED.

Finally, the City of Modesto has begun development and implementation of the “Tuolumne River Regional Parkway”, centered in the City of Modesto. This project includes revision of the Joint Powers Authority General Plan, development of the Gateway Parcel located downtown Modesto near the Ninth St. Bridge, and potentially extensive restoration of riparian zones.

4.5. SUMMARY OF 14 CHANNEL RESTORATION PROJECTS

4.5.1. Special Run Pool 5 Channel Restoration Project

Background

SRP 5 is a remnant instream aggregate extraction area. Prior to aggregate extraction, this site was dominated by a large right bank point bar with diverse riparian vegetation. The point bar was excavated to a depth of 8-10 ft below the low water surface. Presently, the bedload supply to SRP 5 is from local erosion of the bed and banks, and supply is very small. Restoring SRP 5 in conjunction with upstream projects will restore bedload transport continuity from RM 40.3 downstream to SRP 6 at RM 30.6 (more than 30% of the gravel-bedded reach). Bedload can then be used by the river to build and maintain dynamic gravel bars (available for chinook habitat) rather than filling old pits. Restoring SRP 5 is thus an important link to re-establishing fluvial processes in the gravel-bedded reaches of the Tuolumne River.

Additionally, SRP's limit chinook salmon survival because the unnaturally wide channel and deep water conditions offer suitable habitat to non-native largemouth and smallmouth bass, and the native Sacramento squawfish, all of which prey on juvenile chinook salmon. Because a majority of chinook spawning in the Tuolumne River occurs upstream of this location, most juveniles must pass through this reach. Reducing predation should therefore increase Tuolumne River smolt production.

Project Objectives

Special Run-Pool 5 (SRP 5) is located approximately 17 miles east of Modesto and extends from RM 32.9 to 33.4. The project will restore a two-stage channel morphology scaled to the present and future flow regime, facilitate sediment transport and routing, restore chinook salmon habitat, and increase riparian vegetation. Specific objectives of the project are:

- Reduce/eliminate habitat favored by predatory bass species, and replace with high quality chinook salmon habitat.
- Restore channel and planform morphology scaled to contemporary and future sediment and hydrologic regimes.
- Restore sediment transport continuity and eliminate bedload impedance reaches.
- Revegetate reconstructed floodplains and terraces with native woody riparian species, planted on surfaces designed to inundate at discharges appropriate for each species/series life cycles.
- Link restored reaches upstream (Reed site; Gravel Mining Reach) with planned restoration activities downstream (SRP 6) to restore ecological and geomorphological connectivity to reaches containing important chinook salmon habitat.

Project Description

The project will reverse the impact of instream mining by filling the instream pit and restoring an alternate bar sequence through the reach, requiring approximately 175,000 yd^3 of fill material. SRP 5 is located where the valley walls naturally confine the floodway to less than 550 ft wide. Since the valley walls are essentially non-erodible, bank protection is unnecessary. A meander bend will be located against the northern bluff, with a 20 to 30 foot floodplain buffer to allow the channel space to migrate. The design attempts to minimize fill by retaining 8 foot depths to the pools, and restoring only one valley oak terrace. Aggregate should be used to rebuild most of the channel (108,000 yd^3), but topsoil/wash material will be used for floodplain and terrace surfaces (67,000 yd^3).

The proposed design will also re-establish plant series patterns identified during the riparian inventory, including willow and alder stands, Fremont cottonwood, and valley oaks, planted on surfaces successively distant and at higher elevations, respectively, relative to the low water channel. Floodplains should be designed to inundate at approximately the post-NDPP 1.5 to 2.5-yr flood frequency. Cluster planting will create a more natural look to the site, ease watering and maintenance, and increase habitat diversity. Irrigation will be required for two summers. Revegetation materials will come either from on-site sources (valley oak seeds, willow cuttings, cottonwood cuttings), or from local nurseries (sedges, alder, and Oregon ash).

Fluvial geomorphic, riparian and biological objectives of the project will be monitored to assure project performance success. The total estimated cost for SRP 5 implementation is $1,463,000.

For additional details, the complete project conceptual design is available upon request.

4.5.2. Special Run Pool 6 Channel Restoration Project

Background

SRP 6 is a remnant instream aggregate extraction area. Prior to aggregate extraction, the channel had low sinuosity with well vegetated alternate bar sequences. The low water channel was located at the base of bluffs along the north bank, with a large floodplain on the south bank. Aggregate extraction started in the center of the channel and gradually expanded, widening and deepening the channel to its present state. The primary bedload supply to SRP 6 is from erosion of an unmined gravel bar upstream, and supply is very small. Restoring SRP 6 in conjunction with upstream projects (SRP 5; Reed site; Gravel Mining Reach) will restore bedload transport continuity from RM 40.3 downstream to SRP 7 at RM 29.6. Bedload can then be used by the river to build and maintain dynamic gravel bars (available for chinook habitat) rather than filling old pits. Restoring SRP 6 is thus an important link to re-establishing alluvial processes in the gravel-bedded reaches of the Tuolumne River.

Additionally, SRP's limit chinook salmon survival because the unnaturally wide channel and deep water conditions offer suitable habitat to non-native largemouth and smallmouth bass, and the native Sacramento squawfish, all of which prey on juvenile chinook salmon. Because a majority of chinook spawning in the Tuolumne River occurs upstream of this location, most juveniles must pass through this reach. Reducing predation should therefore increase Tuolumne River smolt production.

Project Objectives

Special Run-Pool 6 (SRP 6) is located approximately 14 miles east of Modesto and extends from RM 30.2 to 30.9. The project will restore a two-stage channel morphology scaled to the present and future flow regime, facilitate sediment transport and routing, restore chinook salmon habitat, and increase riparian vegetation. Specific objectives of the project are:

- Reduce/eliminate habitat favored by predatory bass species, and replace with high quality chinook salmon habitat.
- Restore channel and planform morphology scaled to contemporary and future sediment and hydrologic regimes.
- Restore sediment transport continuity and eliminate bedload impedance reaches.
- Revegetate reconstructed floodplains and terraces with native woody riparian species, planted on surfaces designed to inundate at discharges appropriate for each species/series life cycles.
- Link restored reaches upstream with planned restoration activities downstream to restore ecological and geomorphological connectivity to reaches containing important chinook salmon habitat.

Project Description

This project will fill the large aggregate extraction pits and establish a 500 ft wide floodway that conveys flows of at least 15,000 cfs. A meandering alternate bar morphology will be re-established through SRP 6. Two fields located on the right bank were incorporated into the project. These historic floodplain surfaces will be lowered approximately three feet to provide approximately 60,000 yd^3 of fill, decreasing the volume of off-site aggregate needed. Lower design elevations will also allow these floodplains to inundate at more frequent flood recurrences. The remaining aggregate (159,000 yd^3) will likely be provided from off-site sources. Aggregate should be used to rebuild most of the channel, but topsoil/wash material will be used for floodplain and terrace surfaces.

The proposed design will also re-establish plant series patterns identified during the riparian inventory, including willow and alder stands, Fremont cottonwood, and valley oaks, planted on surfaces successively distant and at higher elevations, respectively, relative to the low water channel. Floodplains will be designed to inundate at approximately the post-regulated 1.5 to 2.5-yr flood. Cluster planting will create a more natural look to the site, ease watering and maintenance, and increase habitat diversity. Irrigation will be required for two summer seasons. Revegetation materials will come either from on-site sources (valley oak seeds, willow cuttings, cottonwood cuttings), or from local nurseries (sedges, alder, and Oregon ash).

Fluvial geomorphic, riparian and biological objectives of the project will be monitored to assure project performance success. The total estimated cost for SRP 6 implementation is $2,334,000.

For additional details, the complete project conceptual design is available upon request.

4.5.3. Special Run Pool 9 Channel Restoration Project

Background

At SRP 9, aggregate extraction created a 400 ft wide by 6 ft to 19 ft deep pit, and eliminated floodplains on the north and south banks (Figure 4-6). Restoring SRP 9 in conjunction with SRP 10 will restore bedload transport continuity through this reach, which can be used by the river to build and maintain dynamic gravel bars (available for chinook habitat).

SRPs 9 and 10 are the largest known predator isolation projects on the Tuolumne River, and thus the most expensive to restore. SRP's limit chinook salmon survival because the unnaturally wide channel and deep water conditions offer suitable habitat to non-native largemouth and smallmouth bass, and the native Sacramento squawfish, all of which prey on juvenile chinook salmon. Because a majority of chinook spawning in the Tuolumne River occurs upstream of this location, most juveniles must pass through this reach. Reducing predation should therefore increase Tuolumne River smolt production.

Project Objectives

Special Run-Pool 9 (SRP 9) is located immediately downstream of Fox Grove County Park, 10 miles east of Modesto, and extends from RM 25.6 to 25.9. Specific objectives of the project are:

- Reduce/eliminate habitat favored by predatory bass species, and replace with high quality chinook salmon habitat.
- Restore channel and planform morphology scaled to contemporary and future sediment and hydrologic regimes.
- Restore sediment transport continuity and eliminate bedload impedance reaches.
- Revegetate reconstructed floodplains and terraces with native woody riparian species, planted on surfaces designed to inundate at discharges appropriate for each species/series life cycles.

Project Description

The proposed treatment is to fill most of the pit, and re-establish an alternate bar morphology through the reach. The upstream boundary of the SRP 9 pit (RM 25.9) is a riffle that will act as the project entrance control, and will not be disturbed during construction. The downstream boundary is the riffle crest at the outlet of SRP 9. Modification to the elevation of this outlet control will depend on the gradient through the reach. Restoring a single thread channel and floodplain through the SRP 9 segment will require approximately 146,000 yd^3 of fill material. Imported aggregate at the SRP 9 site will fill the pool along the north and south banks to reclaim a floodplain. A pool-riffle sequence will be constructed, and transition to a riffle at the bottom of SRP 9. The low water channel width will be reduced to a maximum of 100 ft.

The proposed design will also re-establish plant series patterns identified during the riparian inventory, including willow and alder stands, Fremont cottonwood, and valley oaks, planted on surfaces successively distant and at higher elevations, respectively, relative to the low water channel. Floodplains will be designed to inundate at approximately the post-regulated 1.5 to 2.5-yr flood. Cluster planting will create a more natural look to the site, ease watering and maintenance, and increase habitat diversity. Irrigation will be required for two summer seasons. Revegetation materials will come either from on-site sources (valley oak seeds, willow cuttings, cottonwood cuttings), or from local nurseries (sedges, alder, and Oregon ash).

Some restoration activities are proposed for the segment connecting SRP 9 and SRP 10, including filling four backwater areas with an additional 3,500 yd^3 of fill material. The slope through this segment may also be redistributed downstream to increase the gradient through SRP 9 and SRP 10. The sharp meander 1,000 ft upstream of the head of the SPR 10 pool (river turns south) is eroding into an orchard, and this bend will be recontoured to a more gentle bed and revegetated to minimize future bank erosion.

Fluvial geomorphic, riparian and biological objectives of the project will be monitored to assure project performance success. The total estimated cost for SRP 9 implementation is $2,700,000.

For additional details, the complete project conceptual design is available upon request.

4.5.4. Special Run Pool 10 Channel Restoration Project

Background

At SRP 10 aggregate extraction created a 400 ft wide by 36 ft deep in-channel pit, and eliminated the large point bar and floodplains on the north bank (Figure 4-6). Restoring SRP 10 in conjunction with SRP 9 will restore bedload transport continuity through this reach, which can be used by the river to build and maintain dynamic gravel bars (available for chinook habitat).

SRPs 9 and 10 are the largest known predator isolation projects on the Tuolumne River, and thus the most expensive to restore. SRP’s were identified as limiting factors to chinook salmon survival, because the unnaturally wide channel and deep water conditions offer suitable habitat to non-native largemouth and smallmouth bass, and the native Sacramento squawfish, all of which prey on juvenile chinook salmon. Because a majority of chinook spawning in the Tuolumne River occurs upstream of this location, most juveniles must pass through this reach. Reducing predation should therefore increase Tuolumne River smolt production.

Project Objectives

Special Run-Pool 10 (SRP 10) is located one mile downstream of Fox Grove County Park, 9 miles east of Modesto, and extends from RM 25.2 to 25.6. Specific objectives of the project are:

- Reduce/eliminate habitat favored by predatory bass species, and replace with high quality chinook salmon habitat.
- Restore channel and planform morphology scaled to contemporary and future sediment and hydrologic regimes.
- Restore sediment transport continuity and eliminate bedload impedance reaches.
- Revegetate reconstructed floodplains and terraces with native woody riparian species, planted on surfaces designed to inundate at discharges appropriate for each species/series life cycles.

Project Description

The proposed treatment will fill most of the pit, and re-establish an alternate bar morphology through the reach. The project design is to fill the pool primarily from the north bank to create floodplain and native riparian habitat. The low water channel in SRP 10 will be reduced to a maximum width of 100 ft, and will flow along what is now the south bank. The 1997 flood caused damage to the dike on the south bank on private property adjacent to SRP 10, and will require repair during the construction phase to ensure project longevity. The outside of the meander (curving north) along the south bank will be recontoured with a widened floodplain. The proposed channel topography will include three pool /riffle sequences (max pool depth =10 ft). SRP 10 will require 293,000 yd^3 of material, substantially more than SRP 9 because of the greater pool depth.

The proposed design will also re-establish plant series patterns identified during the riparian inventory, including willow and alder stands, Fremont cottonwood, and valley oaks, planted on surfaces successively distant and at higher elevations, respectively, relative to the low water channel. Floodplains will be designed to inundate at approximately the post-regulated 1.5 to 2.5-yr flood. Cluster planting will create a more natural look to the site, ease watering and maintenance, and increase habitat diversity. Irrigation will be required for two summer seasons. Revegetation materials will come either from on-site sources (valley oak seeds, willow cuttings, cottonwood cuttings), or from local nurseries (sedges, alder, and Oregon ash).

Fluvial geomorphic, riparian and biological objectives of the project will be monitored to assure project performance success. The total estimated cost for SRP 10 implementation is $4,657,000.

For additional details, the complete project conceptual design is available upon request.

4.5.5. Gravel Mining Reach Channel Restoration Project (Four phases)

Background

Impetus for restoration in this reach comes primarily from the extensive channel confinement and consequent channel degradation that is occurring throughout this reach. Recurring failure of dikes separating off-channel aggregate extraction pits, accentuated by damage during the 1997 flood has also contributed to degraded habitat conditions. The January 3 flood releases from New Don Pedro Reservoir and spillway peaked at nearly 60,000 cfs. Flood damage occurred not only to the channel and dike system, but also to the aggregate extraction operations, causing millions of dollars in damage and lost revenue. Damage included multiple dike failures, complete channel capture through aggregate pits to the south of the 7/11 Aggregates plant, loss of the M.J. Ruddy conveyor bridge and Roberts Ferry Bridge, damage to plant operation structures, and substantial degradation to salmon habitat (loss of riffles, channel downcutting and fine sediment introduction from the settling ponds). The Districts are requesting the US Army Corps of Engineers to consider increasing the maximum allowable flood release from the present 9,000 cfs to at least 15,000 cfs at Modesto to improve flood control. Substantial upgrades to dikes and increased floodway capacity in this reach is essential.

Project Objectives

The six mile long Gravel Mining Reach is located near Waterford, CA, between Roberts Ferry Road at RM 40.3 and the downstream extent of the contemporary aggregate extraction operations at the George Reed site at RM 34.3. The project reach is divided into four implementation phases based on property ownership boundaries. Multiple objectives of the project include:

- Restore a floodway width that will safely convey floods of at least 15,000 cfs.
- Improve salmon spawning and rearing habitats by restoring an alternate bar (pool-riffle) morphology, restoring spawning habitat within the meandering channel, and filling in-channel mining pits.
- Prevent salmon mortality that results from frequent connection between the Tuolumne River and off-channel mining pits.
- Restore native riparian communities on appropriate geomorphic surfaces (i.e., active channel, floodplains, terraces) within the restored floodway.
- Restore habitats for special status species (e.g., egrets, ospreys, herons).
- Allow the channel to migrate within the restored floodway to improve and maintain riparian and salmonid habitats.
- Remove floodway “bottleneck” created by inadequate dikes (e.g., dike failure above a certain discharge threshold).
- Protect aggregate extraction operations, bridges, and other human structures from future flood damage.

Project Description

The proposed long-term solution is to restore a riparian floodway with a minimum width of 500 ft to 600 ft to safely convey discharges of at least 15,000 cfs with fully grown riparian vegetation and a reasonable safety factor. The project proposes to revegetate floodplains with native riparian series, similar to the revegetation plans described for the SRP projects. The 330 acres of existing ponded wetlands associated with the off-channel aggregate extraction pits will be reduced to 270 acres.

Timeline: because of the large scale of the Gravel Mining Reach project, implementation will occur in four phases, and follow the tentative completion dates outlined below:

- Phase I 7/11 segment to be completed in 2001
- Phase II M.J. Ruddy segment to be completed in 2002
- Phase III Deardorff segment to be completed in 2003
- Phase IV Reed segment to be completed in 2004

Phase I: 7/11 segment

This segment is defined by the extent of 7/11 aggregate extraction upstream of Roberts Ferry bridge (RM 40.3) downstream to the M.J. Ruddy property line below the 7/11 plant site (RM 37.7). Impacts of the 1997 flood included channel capture through aggregate ponds to the south of the 7/11 plant site (RM 39.0 to RM 37.6), river capture of the 7/11 settling pond near the haul road bridge (RM

37.9), and damage to dikes upstream of the 7/11 plant site (RM 38.1 to RM 38.6). For construction of Phase I, a total of 420,000 yd^3 of off-site aggregate material will be imported. The material source site is another 7/11 Materials site on the south bank upstream of Roberts Ferry Bridge. The source and construction sites are connected by off-highway haul roads associated with 7/11 Materials aggregate operations, which run along the south bank. Maximum haul distance is 2.5 miles from the source site to the downstream end of the 7/11 segment. Phase I construction will decrease the channel area within the normal high water boundary of 5,400 cfs (Waters of the U.S. designation) from 84.5 acres to 74.9 acres. Approximately 114 acres of floodplain will be created by moving dikes, importing materials and grading existing sites, increasing the total floodway width to a minimum 500 ft, and flood capacity to convey at least 15,000 cfs. Revegetation of floodplains will increase native riparian habitat from 83.1 acres to 101.1 acres. A total of 24.4 acres of native vegetation (primarily narrow-leaf willow) will be removed as part of channel relocation and/or to acquire revegetation materials; 1.1 acres of exotic vegetation will be removed.

Phase II: M.J. Ruddy segment

This segment is defined by the property line upstream of Joe Ruddy's orchard (RM 37.7) downstream to Santa Fe Aggregates haul road bridge (RM 36.6). The 1997 flood cauksed extensive damage to the 4-Pumps restoration project reach, connecting the river to south bank ponds at RM 37.1, RM 36.6, and RM 36.2, and connecting a north bank pond at RM 36.7. Construction in the M.J. Ruddy Phase II segment will require importing an estimated 465,000 yd^3 of aggregate and topsoil material. Construction will decrease the channel area within the normal high water boundary of 5,400 cfs (Waters of the U.S. designation) from 38.7 acres to 32.0 ft. Approximately 36.4 acres of floodplain will be created or modified to increase the floodway capacity, and native riparian habitat will be increased from 18.6 acres to 42.2 acres. A total of 1.6 acres of native vegetation (narrow-leaf willow) will be removed as part of channel relocation and/or to acquire revegetation materials.

Phase III: Warner/Deardorff segment

The Warner/Deardorff segment is defined by the Santa Fe Aggregates haul road bridge (RM 36.6) downstream to the entrance to Dan Casey Slough (RM 35.2). Damage by the 1997 flood consisted of numerous dike failures on the south bank downstream of the haul road bridge, destruction of Santa Fe Aggregates conveyor bridge, and connection of the Tuolumne River to the Tulare Pond at flows greater than 2,000 cfs. Construction in this segment may require no material importation, but will relocate large volumes of on-site materials. Haul roads are available on both sides of the river. Construction will increase the channel area within the normal high water boundary of 5,400 cfs (Waters of the U.S. designation) from 39.0 acres to 42.2 acres. This phase will also create approximately 63.6 acres of floodplain. Native riparian vegetation will increase from 56.9 acres to 67.5 acres. A total of 9.0 acres of narrow-leaf willow will either be disturbed or removed as part of channel relocation and/or to acquire revegetation materials.

Phase IV: Reed segment

The Reed segment is defined by the entrance to Dan Casey Slough on the upstream end (RM 35.2), and the upstream extent of the Reed Mitigation restoration project on the downstream end (RM 34.3). Damage during the 1997 flood was limited to the upstream and downstream ends of the existing south bank pond at RM 34.5. Similar to the Tulare Pond excavation in phase III, the Reed segment restoration may excavate materials purchased and available on-site for all channel and floodplain reconstruction. Construction will increase the channel area within the normal high water boundary of 5,400 cfs (Waters of the U.S. designation) from 22.7 acres to 25.4 acres. Restoration will create approximately 48.2 acres of floodplain. Native riparian vegetation will be increased from 35.9 acres to 47.5 acres. A total of 2.9 acres of native vegetation (narrow-leaf willow) will be removed as part of channel relocation and/or to acquire revegetation materials.

Fluvial geomorphic, riparian and biological objectives of the project will be monitored to assure project performance success. The total estimated cost for Gravel Mining Reach implementation is $23,669,000. Funding for Phases I and II have been provided by USFWS-AFRP and CALFED; funding for Phases III and IV has not yet been received, but project approval and funding availability will likely affect the timeline for completion of these phases.

For additional details, the complete project conceptual design is available upon request.

4.5.6. Tuolumne River Sediment Management and Implementation Plan

Background

Construction of La Grange Dam in 1893 (RM 52.0) permanently ended coarse sediment supply to the Tuolumne River channel downstream of La Grange Dam. Because the few small tributaries entering the Tuolumne River downstream of La Grange contribute virtually no coarse sediment, coarse sediment available for downstream transport is currently limited to sediment stored in contemporary channel, floodplain, and terrace deposits, or bank erosion of dredger tailings. In the absence of an upstream source, high flow events have selectively transported medium-sized particles (gravels) from the bed surface, removing gravel bars and leaving behind large cobbles and boulders that armor the bed surface layer. Additionally, fine sediment (sand and silt) input and storage into the Tuolumne River has increased in recent years, as a result of tributary inputs and the January 1997 flood.

Fine sediment stored in spawning gravels reduces survival of salmonid embryos. Chinook salmon depend on an adequate quantity of high quality coarse sediment deposits for spawning and rearing, and require a significant portion of these deposits to be of gravel and small cobble size classes with relatively low proportions of fine sediment. The reduced quantity and quality of spawning habitat has reduced the productive capacity of Tuolumne River spawning reaches, and has concentrated chinook salmon in short reached below La Grange Dam that contain the relatively highest quality spawning gravels.

Actions to reverse past trends in sediment supply imbalances by balancing coarse sediment supply and downstream routing and reducing fine sediment input have the potential to increase salmon production in the Tuolumne River and achieve chinook salmon production targets set for the Tuolumne River.

Project Objectives

This sediment management plan presents four objectives:

- increase coarse sediment storage in the channel with a large “transfusion” of coarse sediment to provide alluvial deposits immediately available for chinook salmon spawning, and for eventual downstream transport and redeposition;
- maintain this restored coarse sediment storage by periodic augmentation of coarse sediment supply equal to the rate of downstream sediment transport;
- implement remedial actions to prevent further extensive fine sediment input into the Tuolumne River from Gasburg Creek (located near the upstream end of the spawning reaches);
- implement actions to reduce fine sediment storage in the mainstem Tuolumne River.

Project Description

The purpose of this project is to develop and implement a comprehensive sediment management plan for the gravel-bedded reaches of the Tuolumne River to restore coarse sediment supply and reduce fine sediment input into the river. Four crucial tasks for restoring and maintaining a balanced sediment budget are identified: Task 1 will develop a sediment management and implementation plan that includes design, implementation, adaptive management, and the monitoring required for adaptive management. Task 1 also includes refinement of a chinook salmon juvenile production model developed by the Districts that can be used to predict the benefits of sediment management toward salmon production. Task 2 will continue a program of coarse sediment augmentation (begun by CDFG), including refinement of proposed introduction sites, introduction volumes, and monitoring protocols. Task 3 will initiate a program for fine sediment reduction, by: (1) reducing fine sediment supplied to the upper river from the Gasburg Creek watershed, (2) evaluating alternative methods for fine sediment reduction/removal in the mainstem Tuolumne River, and (3) implementing fine sediment removal from the mainstem channel. Task 4 will develop an adaptive management and monitoring program for quantifying coarse sediment transport to provide volume estimates for annual augmentation, to maintain coarse sediment storage in the mainstem channel.

The total cost for this project, including project management, planning, and implementation, is $414,500. Costs for future coarse sediment management will depend on the magnitude, frequency, and duration of gravel transporting high flow events. Replacing the quantity of gravel transported out of the gravel-bedded reaches would cost more during wet years than during dry years years when flows do not transport appreciable quantities of coarse sediment, and gravel augmentation is not required.

This proposal contains revised designs for a Gasburg Creek Sedimentation Basin.

For additional details, the complete project conceptual design is available upon request.

4.5.7. Dredger Tailing Reach Channel Restoration Project (Three phases)

Background

The Dredger Tailing Reach restoration project is located in the heart of the gravel-bedded zone between river miles (RM) 42.5 and 46.8 (Reach 6 of the Restoration Plan). This reach was severely degraded by gold dredgers in the early- to mid-1900s, and combined with flow and sediment regulation, has not significantly recovered in the following decades. The Dredger Tailing Reach contains chinook salmon spawning riffles which are degraded, of poor quality, and receive significantly less spawning use than spawning areas further upstream. Within its current physical constraints, this reach cannot recover to a desirable state on its own, but offers real opportunity for restoring natural channel and floodplain features, chinook spawning and rearing habitats, and reducing predator populations.

Project Objectives

The overall goal of this project is to convert a fossilized, highly degraded, remnant channel back into a dynamic meandering channel. Primary objectives include:

- Rebuild a natural channel geometry scaled to current channel-forming flows.
- Allow the channel to migrate within the restored floodway to improve and maintain riparian and salmonid habitats.
- Restore and increase salmon spawning and rearing habitats by restoring an alternate bar (pool-riffle) morphology, restoring spawning habitat within the meandering channel.
- Eliminate salmon stranding problems associated with backwaters and sloughs, and floodplain “traps” accessed during moderate flows.
- Acquire adjacent floodplain properties from voluntary land owners, either through purchase or conservation easements. The Bobcat Flat Land Acquisition currently being negotiated is an excellent example of the type of opportunity available within the Dredger Tailing Reach.
- Restore native riparian communities on appropriate geomorphic surfaces (i.e., active channel, floodplains, terraces) within the restored floodway.
- Restore riparian canopy habitats for other endemic wildlife species (e.g., egrets, ospreys, herons).

Project Description

The large size of this reach requires that implementation occur in three phases, similar to project phasing in the Gravel Mining Reach. The reaches were delineated by unique restoration objectives and sections of channel that will require little or no restoration (natural delineation breaks).

Phase I: Zanker Reach (RM 45.4 to 46.5)

The upstream portion of this reach is long and straight, confined by encroached riparian vegetation (RM 46.0 to 46.5). Immediately downstream, the riparian vegetation is less confining and the valley confinement decreases (RM 45.4 to RM 46.0). During high flow events, the bed surface in the confined section incises, with scoured material depositing and aggrading where confinement ceases. The result is a long deep chute-like reach upstream with functionally no alluvial deposits, and an aggraded bar downstream that backs water upstream into a “lake.” The riffle is over-steepened to the point where preferable spawning depths and velocities are in the tail-out area and the margins of the steep riffles. Proposed activities in the unconfined section including excavating a large portion of the bar to restore natural riffle gradient, using excavated materials to build bankfull confinement locally and fill portions of the channel in the upstream section.

Activities in the upstream section may include filling portions of the confined low flow channel to pre-flood elevations, removing selected portions of the riparian berms to increase bankfull channel sinuosity, and constructing point bars opposite those locations to further encourage sinuosity. Although some on-site construction materials are available, significant fill material may be need from off-site sources. Riparian revegetation will occur during and after channel construction.

Phase II: Peaslee Creek Reach (RM 43.8 to 45.4)

The Peaslee Creek Reach is solely a remnant of gold dredger activities and aggregate removal for constructing the NDPP. The channel is often deep and multi-channeled, following a tortuous course in the general downstream direction. Excavated “floodplain” surfaces are at reasonable post-NDPP floodplain elevations, but the “bankfull” channel is extremely wide due to the remnant dredger-created channel. Additionally, the dredger mining left extremely steep riffles that provide poor salmon spawning habitat. Proposed activities include recreating a single thread low flow and bankfull channel through the reach, redistributing channel gradient through the reach to restore low gradient riffles, increasing bankfull channel sinuosity, restoring functional floodplains, and revegetating with native riparian vegetation. Salmon spawning habitat should be greatly increased by implementing this project. There is essentially no construction materials on-site, so material would have to be imported from other sources.

Phase III: Hall Reach (RM 42.2 to 43.8)

The Hall Reach is very similar to the Peaslee Creek reach, with the exception of having adequate construction materials in the form of dredger tailings at RM 43. Proposed activities will again include recreating a single thread low flow and bankfull channel through the reach, redistributing channel gradient through the reach to restore low gradient riffles, increasing bankfull channel sinuosity, restoring functional floodplains, and revegetating with native riparian vegetation. Salmon spawning habitat will again be greatly increased by implementing this project.

A cost for implementing this project has not been estimated due to continuing TRTAC discussion on specific restoration approaches, and evolving landowner interest in conservation easements and/or fee-title purchases.

For additional details, the complete project conceptual design is available upon request.

4.5.8. Basso Spawning Reach floodplain restoration (RM 47.6 to 50.5)

Background

A 60-year legacy of gold mining, grazing, and dam construction has resulted in fragmented riparian stands, poor or non-existent valley oak and cottonwood regeneration, fossilized alluvial deposits, remnant pits that periodically strand juvenile chinook salmon during receding high flows, and reduced spawning gravel storage within the bankfull channel. Extensive gold dredging (from valley wall to valley wall) occurred through the 1940’s, leaving no defined channel, and voluminous dredger tailings piled on floodplain surfaces. Flood events after 1937 began reinitiating a defined channel through the tailings, but by 1963 the channel still lacked defined floodplains and meander sequences. These dredger tailings were removed for the construction of New Don Pedro Dam from 1965 to 1970. Their removal left shallow pits and non-draining surfaces. After New Don Pedro Dam was completed in 1971, the channel between river mile 50.5 and 46.6 was reconstructed to improve chinook salmon spawning habitat. However, riparian vegetation and floodplains were not restored, and cattle grazing and flow regulation has discouraged riparian regeneration at the site. White alder and narrow-leaf willow have encroached onto point bars, partially fossilizing these alluvial deposits. Lastly, the 1997 flood deposited tens of thousands of cubic yards of sand in the reach. The interaction between floodplain elevation, riparian vegetation and a contemporary bankfull discharge must be restored.

The cumulative impacts of these changes to chinook salmon habitat has been amplified because this reach has the highest concentration of spawning in the river, and possibly the highest concentration of juvenile rearing. Significant stranding periodically occurs in this reach during high flows because many of the floodplain undulations and pits do not drain back to the river, so as high flows recede, fry and juvenile chinook salmon are stranded and die in these areas. The remnant dredger tailing surface is comprised of large cobbles, gravels, and sand, which prohibits natural riparian regeneration. Additionally, substantial loss of the high flow regime has further discouraged riparian regeneration. Finally, the large volume of sand deposited by the 1997 flood has greatly increased sand storage in the reach, possibly leading to short-term and long-term negative impacts to chinook salmon habitat.

<u>Project objectives</u>

Objectives for the Basso Spawning Reach Floodplain Restoration Project are:

- Increase woody riparian vegetation coverage.
- Improve natural regeneration of Fremont cottonwood, valley oak, tree willows and alder.
- Remove invasive exotic hardwood vegetation.
- Reduce juvenile chinook salmon stranding.
- Reduce fine sediment (sand) storage in the floodway.
- Restore functional floodplains.

<u>Project description</u>

The project objectives will be achieved by regrading the remnant dredger tailing surfaces into functional floodplains, and revegetating these restored floodplain surfaces. Specific components include:

1) *Regrade floodway surfaces outside the low flow channel to inundate at 4,000 to 5,000 cfs, thereby increasing bed mobility and recreating a functional floodplain.*

   Remnant dredger tailing surfaces will be regraded to fill in many of the stranding pits. Other stranding pits and undulations will be regraded so that if flows access them, water will drain back to the river and reduce chinook salmon stranding. Sand deposited on floodway surfaces during the 1997 flood will be preferentially targeted for removal and spoils in pits further away from the channel so the sand will not be re-introduced into the river for many years. Local areas of high ground and old tailings will also be used as on-site fill material to fill pits. We anticipate near 100,000 yd^3 of earthwork will be required, with all materials derived on-site.

2) *Plant native riparian hardwoods on floodway surfaces appropriate for each species life history requirements.*

   After earthwork is completed, valley oak, Fremont cottonwood, and willows will be planted on floodplain surfaces appropriate for their life history requirements. Floodplain species will be willows, alders and cottonwoods. Willows will be planted nearer the active channel-bankfull channel transition, while valley oaks will be planted on higher floodplains and terraces near the vr valley walls. Revegetation patterns will reflect plant species patterns identified during the riparian inventory conducted in 1996.

   Because of cost, material supply, and species characteristics, some hardwood species have priority over others. Cottonwood and willow plantings on floodplain surfaces are prioritized because of their fast growth, structural contribution to the riparian corridor, and aesthetics. Valley oaks are the next priority because of their large-scale removal over the past 100 years. Increasing the valley oak stand size is desirable, not only for their long-term wildlife habitat contribution, but also for the valuable structural components they add to the riparian corridor.

   Much of the revegetation materials will come from on-site sources (valley oak seeds, willow cuttings, cottonwood cuttings), and species not found on-site (sedges, alder, and Oregon ash) should be purchased from local nurseries who obtain it from within the Tuolumne River corridor. Cluster planting (vegetation patches) rather than row planting should be encouraged to re-create a more natural site appearance, ease watering and maintenance, and increase habitat diversity.

3) *Remove invasive exotic vegetation.*

   All woody exotic plant species within the reach should be removed during floodplain regrading. Three plant species should be targeted for removal: giant reed, tree of heaven, and all Eucalyptus species. The San

Joaquin River Management Program Advisory Council has identified giant reed as a plant to eliminate throughout the San Joaquin River and its tributaries (SJRMP 1995). Eucalyptus sp. has been planted and naturalized throughout the lower project reach. To ensure that re-sprouting does not occur, the above ground portion and the stump/root wads of exotic plants must be removed. After initial removal, exotic species should be removed in perpetuity because these plants prevent native species from naturally recruiting and establishing.

4) *Preserve existing riparian vegetation.*

Preserving as much existing native woody riparian vegetation as feasible is a primary goal of the project. Cottonwood, tree willow, and valley oak stands should not be removed during construction. The valley oaks that are present in this reach will be utilized for seed collection, and are important contributors to future recruitment. Nearly all cottonwoods should be preserved to increase age class diversity and riparian canopy structure. Mature cottonwoods (>25 years), regardless of stand size, should not be removed because they provide the seed source for future recruitment. A few smaller stands (<2 acres) of cottonwoods that impede floodplain regrading may be removed, but should be salvaged to provide necessary plant material for revegetation.

The total cost for the project will depend on the final design; conceptual designs estimate implementation costs of approximately $2,000,000. This cost estimate is based on regrading of approximately 100,000 yd^3 of on-site materials, and replanting of approximately 50 acres on restored floodplains. No land purchase or easments were included in this cost estimate.

For additional details, the complete project conceptual design is available upon request.

5. ADAPTIVE MANAGEMENT

The adaptive management approach outlined as Adaptive Environmental Assessment and Management (AEAM) (Holling 1978) has received extensive scientific peer review, and should be the strategy sought by the Technical Advisory Committee. This approach stresses explicit integration of scientific, economic and social concerns into efforts addressing resource problems. Computer modeling and simulation are employed to demonstrate the potential effects of alternative management actions and scientific uncertainty. Stakeholders, all bringing their own political, economic, and cultural concerns, come together in an analytical process aimed at identifying appropriate cases for scientific investigation. Hypotheses and management objectives are outlined with prudence and deliberation (i.e., conservatively).

Effective adaptive management must manage processes not trends. All too often, monitoring is fashioned with ‘time’ on the X-axis, with the dependent variable (Y-axis) as a response variable, often biological. Trend monitoring does not target processes that cause the trend, making cause-and-effect links difficult and qualitative. Additionally, trend monitoring often takes years to reveal a consistent trend (e.g., escapement), and usually is a function of several interrelated factors.

To make and/or refine management recommendations, other variables must be on the X-axis. In other words, *adaptive management must be driven by hypothesis testing to explain causative processes.* This generally means replacing the X-axis with something other than ‘time.’ For example, implementing a restoration strategy such as spawning gravel introduction will require quantifying the benefits of this activity to the river ecosystem or chinook salmon, such as increased spawning gravel availability or improvements in gravel permeability, which can then be extended to quantify the benefit to smolt production or survival. Trend monitoring objectives should not be discarded, but must be integrated with monitoring protocols that have ‘process’ on the X-axis.

In addition, adaptive management must acknowledge the uncertainty about the system and resources being managed, favoring actions that are reversible. Walters and Holling (1990) note that defining testable hypotheses is trivial, but generating hypotheses sensitive to changes in the function or processes of the ecosystem is much more complex. Restoration actions may shift limiting factors from one constraint to another, confounding the interpretation of experimental results, even though improvements were realized. They suggest a blend of “scale-constrained models, scale-unconstrained process knowledge, good old-fashioned natural history and active adaptive management.”

The first and primary objective of an adaptive management plan is to define policy and management objectives. We believe that the Attributes of River Ecosystem Integrity (presented in Chapter 2) provide a foundation for management objectives. as an integral component.

The second objective is to document the status and trends in chinook salmon population dynamics, continuing with the outlined FERC-mandated monitoring plan. These biological objectives should include all in-river salmon life stages, be habitat based, and should target preventing large population crashed such as occurred in response to drought years.

The third objective, intertwined with the first two objectives, is to define restoration endpoints:

- What is/will be meant by “self-sustaining” ecosystem processes? Can we achieve this, or will human intervention be necessary indefinitely?
- How much can we expect anadromous salmonid habitat or population levels to respond (and improve) to restoration activities?
- Can we restore the processes that sustain natural regeneration of riparian vegetation?

These questions will be critically important as the Restoration Plan is implemented.

Successful adaptive management requires a process for identifying and evaluating science-based hypotheses, and then formulating strategies to meet management objectives. Adaptive management also requires a sound monitoring plan to provide the scientific basis for changing management strategies. In other words, a strong feedback loop that includes formulation of hypotheses, implementation, monitoring, management evaluation, and finally, management response, is fundamental. Because restoration activities will be substantial in the coming years, two roles of monitoring are needed: river-wide and restoration project-specific. We emphasize that the recommendations and framework for adaptive management provided by this monitoring plan provide only the scientific basis for implementing monitoring, while the task of defining policy and management objectives (Objective 1) is left to the Technical Advisory Committee.

5.1. MONITORING

The purpose of the Tuolumne River Monitoring Program is to provide a quantitative basis for evaluating the success of management actions implemented under the FERC Settlement Agreement adaptive management strategy, and for determining whether the “comparative goals” set forth in the Settlement Agreement are met (TID 1998).

While an extensive foundation of information already exists for the Tuolumne River, perhaps more complete than most other Central Valley rivers, there is nevertheless a need for more information to assess the success of future restoration and management actions. Careful planning and documentation are essential.

Despite substantial information generated over the past years on the Tuolumne River, geomorphic and physical-process data have received less attention. Past monitoring, along with FSA-prescribed monitoring focus on chinook salmon production, survival, and population levels. No monitoring program has been developed to assess physical processes that maintain river conditions and integrate chinook salmon objectives and restoration activities. We propose objectives and suggest a framework for a river-wide monitoring program that incorporates objectives of the FSA, the Draft Monitoring Program developed by the Districts, and project-specific monitoring associated with restoration projects such as the SRP 9/10 and Gravel Mining Reach projects.

In addition to river-wide monitoring objectives, Section 12 of the FSA requires a program that integrates with site-specific monitoring designed to evaluate specific project objectives. The monitoring program should be approved by the TRTAC (i.e., TRTAC should evaluate and approve or modify the information presented here). Section 13 requires the Districts, in cooperation with CDFG, USFWS, and CCSF, to monitor the fall-run chinook salmon and their habitat. Many components of Section 13 monitoring have been implemented or are scheduled to be implemented in the near future. In addition to river-wide monitoring required by the FSA, agencies issuing permits or providing funds to implement restoration program components require site-specific monitoring to assure that project objectives and desired benefits are achieved, and negative impacts are avoided or mitigated. Monitoring identified in the FSA Sections 12 and 13 consists of these two integrated components: a river-wide component and a restoration site-specific component. These two components are summarized as:

The river-wide component should assess large-scale processes, characteristics, and trends, providing information necessary to evaluate the overall effectiveness of flow and non-flow management measures. The monitoring specified in FSA Section 13 focuses on assessing salmon population dynamics, habitat utilization, and the success of the restoration program in restoring the population to acceptable levels and increasing the population's resiliency on a river-wide basis. In addition to habitat and salmon population parameters to be monitored under FSA Section 13, the river-wide component may include assessment of fluvial and ecological processes and responses of river, floodplain, and riparian ecosystems to those processes as a result of FSA Section 12 restoration efforts. For example, monitoring may document that the restoration program increased spawning and rearing habitat quantity and quality, reduced habitat for introduced predatory fish, and increased riparian vegetation cover. The Section 13 monitoring program would assess whether this improvement in physical habitat resulted in improved salmon production or recruitment.

The restoration site-specific component should evaluate and measure the success of specific restoration projects. The river-wide component assesses fluvial geomorphic and ecological processes and response to restoration measures at the scale of the entire river corridor or reach, while the site-specific component assesses similar questions within or near the spatial boundaries of a specific restoration project. For example, site-specific monitoring for a channel restoration project might assess sediment transport through the reconstructed channel, the performance of the designed bankfull channel, changes in egg emergence success, and germination of native riparian vegetation within the site. Site-specific monitoring will be as important on the Tuolumne River as river-wide strategies to evaluate the efficacy of restoration actions, and then refine, recommend, or re-prioritize activities in other directions. Sites-specific monitoring could also be funded by outside funding sources, addressing issues that compliment FERC monitoring but are not currently funded by the FSA. This site-specific information can be used for a river-wide assessment.

Below we present river-wide monitoring protocols to illustrate the broad range of information needs, and to aid in prioritizing monitoring objectives. These protocols incorporate those mandated by the FSA, and also incorporates monitoring that integrates physical processes with riparian and fisheries resources. This monitoring plan is not intended to be exhaustive, acknowledging that many finer-scale ecological processes are beyond the scope of this Plan.

5.2. RIVER-WIDE MONITORING PROTOCOLS FOR EVALUATING FLUVIAL PROCESSES AND SALMONID POPULATION RECOVERY

SEDIMENT BUDGET AND ROUTING

- Document thresholds for channelbed mobility, related to flood frequency;
- Document changes in instream gravel storage to ensure salmonid spawning and rearing habitats are not limited by gravel availability;
- Document fine and coarse bedload transport rates as a function of discharge magnitude, duration, and frequency in the gravel-bedded reaches, combining field sampling and modeling;
- Document occurrence and future formation of large-scale alluvial features, e.g., point bars;

CHANNELBED DYNAMICS AND MORPHOLOGY

- Document changes in channel morphology (e.g., riffle loss, channel downcutting or aggradation, channel migration, cross sectional adjustments, channelbed surface composition);
- Document the extent (scour depth) and frequency of channel-bed surface mobility, spawning gravel deposits, and larger alluvial features (e.g., point bars) as a function of annual high flow magnitude, duration and frequency;

FLOODPLAIN AND RIPARIAN DYNAMICS

- Document increases in areal extent of functional floodplain (suitable for dynamic cottonwood development);
- Record status of encroached alders along channel margins of selected index reaches. (considerable mortality occurred prior to the January 1997 flood presumably from prolonged inundation by higher baseflows);
- Document volume and areal extent of fine sediment deposition on floodplain surfaces related to flood frequency;
- Document species diversity, age class composition, and physical microclimate of riparian communities on selected floodplains and low terraces, including temperature reduction and increased humidity within the riparian canopy. Large stands of trees that can modify microclimate have conspicuously higher relative humidity inside the stand than outside, and can better sustain riparian-dependent plant and animal communities.

SALMON SPAWNING AND REARING HABITAT

- Document river-wide spatial and temporal changes in spawning gravel quality (via particle size analysis and/or permeability or other similar methods) resulting from larger and more frequent high flow releases and reduced fine sediment supply;
- Document river-wide spatial and temporal changes in spawning habitat quantity (using a systematic habitat classification system and high resolution aerial photographs in field) resulting from larger and more frequent high flow releases and greater gravel supply;
- Document occurrence and quality of juvenile chinook rearing habitat in relation to selected sites with alluvial features, rip-rapped banks, etc. by mapping potential habitat for target species. A subset of these sites could serve as control sites for evaluating success of specific channel reconstruction projects;
- Evaluate the heterogeneity (complexity) of habitat in relation to variable flows at the microhabitat and macrohabitat levels;
- Integrate fluvial geomorphic restoration objectives (e.g., gravel management program) with chinook habitat (e.g., spawning habitat) by quantifying habitat availability in relation to geomorphic features (e.g., alternate bars);

SALMON POPULATION DYNAMICS

- Estimate survival (reach and river-wide) and production, physiological condition, origin (wild or hatchery), and timing of downstream migrating smolt populations;
- Estimate adult escapement with annual spawning surveys, or an adult counting station;
- Document spatial and temporal trends in redd construction, superimposition, and abundance;
- Evaluate genetic composition of Tuolumne River salmon stocks;
- Document salmonid straying from nearby rivers (from carcass surveys);
- Perform scale analyses to estimate smolt size that produces the highest proportion of adult spawners;
- Refine and implement the salmonid population model and/or other strategies to continually evaluate limiting factors;

OTHER FISH POPULATIONS

- Document annual population trends for Sacramento squawfish, largemouth bass, smallmouth bass, and others, using index reaches distributed throughout the lower Tuolumne River;
- Document spawning habitat location, extent, and seasonal utilization of largemouth bass and smallmouth bass;
- Document relationship between water temperature and largemouth bass recruitment;

WILDLIFE POPULATIONS

- Document location, seasonal utilization, site characteristics, and population size in heron and egret rookeries, osprey nest sites, (and other wildlife species, especially listed species) within the riparian corridor;
- Record influence of riparian corridor width on wildlife species diversity (presently, no one can recommend a minimum riparian corridor width appropriate to the Tuolumne River corridor that restores and maintains riparian plant and animal communities because no monitoring data have been collected that target this concern);
- Inventory occurrence and utilization of large snags in the riparian corridor;
- Survey index reaches for inventorying amphibian species diversity and populations;
- Survey index reaches for inventorying macroinvertebrate species diversity and populations;

WATER QUALITY

- Continuously record ambient water temperatures from La Grange Dam to the San Joaquin River confluence;
- Continuously record ambient water temperature in potential thermal refugia during summer and early fall;
- Evaluate variations in water temperature at the microhabitat level (e.g., determine if water temperatures in pools are stratifying, and if thermal stratification is a function of river discharge);
- Document seasonal patterns of dissolved oxygen concentration and turbidity throughout the lower Tuolumne River and at suspected point sources;
- Develop a program to evaluate sources and impacts of pesticide, herbicide and hydrocarbon runoff on the aquatic community in the mainstem Tuolumne River;
- Monitor discharge from Dry Creek to assess water quality effects on Tuolumne River mainstem;

INTEGRATION

- Integrate disparate information needs into cohesive monitoring plan.

Obviously a comprehensive monitoring plan must be more than simply lists of data collection protocols or sampling strategies. With no cohesive strategy, data collection will follow management actions instead of lead them, as an adaptive management plan would require. Integrating or synthesizing information needs into a well organized strategy to collect, interpret, then revise objectives is the single most important step in developing a monitoring plan.

As an initial step, conceptual models should be developed that integrate existing experience and scientific information and are capable of making predictions about the river system, and about the impacts of alternative policies or actions. These models can then identify key knowledge gaps that make model predictions questionable. These gaps should be a primary target of monitoring, with the intention of fortifying the model, and therefore our understanding of how the river works.

As an example, the Districts developed a stock-recruitment model (EA 1992, 1997) for the San Joaquin River chinook salmon population to explain the dynamic fluctuations in population levels, and to explore the role of environmental (mortality) factors in explaining these fluctuations. Once calibrated, the model can predict chinook salmon population changes to “adaptive management or restoration activities” such as spring pulse flows, increased availability of high quality spawning habitat, decreased bass predation, or improvements in water quality. These predictions can then help prioritize management strategies. The predictions are then tested by monitoring and field experimentation. The salmon population model, like all models, has weaknesses. Adult escapement estimates for the San Joaquin River basin tributaries could be replaced by actual escapement counts by constructing a fish weir or other trapping/counting procedure, to eliminate uncertainty in the estimation of these model parameters. These counts can then be used to calibrate carcass survey estimates. Other weaknesses of the model include the accurate aging of returning adults, and an accurate means of evaluating juvenile production, both of which would increase the utility of this model as a management tool.

In addition to chinook salmon models, process-based models are essential in making management decisions. Process-based models can often be calibrated more precisely than biological models. For example, a central feature of the Restoration Plan is restoring coarse sediment supply and bedload transport processes in the upper Tuolumne River spawning reaches, with the explicit goal of improving spawning habitat. Balancing coarse sediment supply with higher discharges capable of mobilizing and transporting coarse sediment is an essential feature of this restoration strategy, and should be accomplished by a combination of field measurements and modeling. Spawning gravel management to improve habitat availability and egg survival-to-emergence can be field tested (e.g., with permeability methods currently being developed). The important point is that policy or management decisions must be made as explicit, testable hypotheses that are then evaluated to determine their efficacy. Models can provide the foundation for determining which hypotheses (management actions) have the best chance of succeeding and forecasting their effects on salmon production.

5.3. CHINOOK SALMON MONITORING UNDER THE FERC SETTLEMENT AGREEMENT

The Districts have developed a monitoring plan (TID 1998) designed to meet chinook salmon monitoring requirements of the FERC Settlement Agreement. This plan is incorporated here as a foundation for continued monitoring of the chinook salmon population and habitat in the Tuolumne River.

5.3.1. River-wide monitoring (FSA Section 13)

The chinook salmon monitoring plan (Section 13) focuses on salmon biology, water temperature, and spawning habitat quality. Information on other fish species is also gathered in this monitoring. The Districts have also developed a proposal (TID 1997) to integrate monitoring of fry, juvenile, and smolt life stages. The proposal includes three main components: (1) monitoring chinook salmon size, distribution, abundance, migration, production, and survival; (2) assessing rearing conditions in the San Joaquin River, and (3) completing the flow fluctuation and stranding assessment for fry and juvenile salmon.

The fry, juvenile, and smolt monitoring proposal (TID 1997) incorporates the Comprehensive Assessment and Monitoring Program (CAMP) directed by the US Fish and Wildlife Service, which will document fry, juvenile, and smolt production from the Tuolumne River as well as emigration timing and the effects of various factors on emigration timing. The CAMP assessment will be based on data collected at a rotary screw trap installed near the mouth of the Tuolumne River. The trap will be monitored from January 1 through June 30 each year. A detailed description of the trap monitoring protocol is in Standard Protocol for Rotary Screw Trap Sampling of Outmigrating Juvenile Salmonids (USFWS 1997).

Monitoring chinook salmon migration, production, and survival would be based on the operation of two rotary screw traps, one near the downstream end of the spawning reaches (and corresponding with the upstream end of the Gravel Mining Reach), and one at the downstream end of the Gravel-bedded Zone. Sampling procedures would follow CAMP protocols (USFWS 1997). The following hypotheses would be tested:

- Fry, juveniles, and smolts emigrating from the Tuolumne River experience significant mortality before reaching the San Joaquin River.
- Fry, juveniles, and smolts rearing and emigrating from the Tuolumne River may experience higher mortality in the mined reach (from near Turlock Lake State Recreation Area (TLSRA) to Hughson Sewage Treatment Plant) than in the downstream reach (from Hughson Sewage Treatment Plant to Shiloh Road) or the spawning reach upstream of TLSRA.
- Migration timing and rate are influenced by environmental factors, including flow magnitude, flow changes, turbidity, and/or water temperature.
- Migration timing is influenced by smolt size.
- Fry and juvenile salmon are unequally distributed in the lower river.
- Distribution of rearing juveniles is influenced by environmental factors, including flow magnitude, turbidity, and/or water temperature.

- Distribution of rearing juveniles is influenced by fish size.

5.3.2. Site-specific monitoring objectives

Site-specific monitoring (related to implementation of restoration projects) offers the opportunity to address river-wide objectives at a site-specific scale. Information gathered to assess project objectives can be designed to address broader objectives and knowledge gaps. While site-specific monitoring objectives should target restoration project objectives, they should include a river-wide perspective. For example, smolt survival studies designed to evaluate the SRP 9/10 Channel Restoration Projects were integrated into the river-wide monitoring to achieve multiple objectives and share monitoring costs. This approach is encouraged wherever practicable.

In general, site-specific monitoring will assess whether: (1) the intended physical features were constructed as designed, (2) the hydraulic and fluvial processes function as intended, (3) targeted biological taxa and communities (especially salmon) receive intended benefits, and (4) these biological and physical components, once restored, will be self-sustaining in the future hydrologic regime.

5.3.3. Summary of completed, ongoing, and proposed monitoring efforts (in addition to FSA section 13)

The TID/MID, CDFG, and USFWS conducted extensive monitoring on the Tuolumne River prior to the 1995 FSA as part the Don Pedro Project FERC Fish Study Programs and other investigations. In addition, analyses of fluvial geomorphic and ecological processes are included in this Restoration Plan.

Three monitoring components are described below. The smolt survival monitoring program currently being implemented on the Tuolumne River includes two independent, integrated strategies: (1) large coded-wire tagged juvenile and smolt releases to assess the relationship between survival during outmigration, and concurrent streamflows, and (2) a multiple-marked recapture strategy designed to provide reach-specific outmigration survival and timing data. Implementation of this strategy is tentatively scheduled to continue during the next two years, but is currently under close review by the Technical Advisory Committee.

The assessment of rearing conditions in the San Joaquin River would include a two-year reconnaissance-level survey to: (1) develop a suitable base map of habitat, (2) review literature, (3) evaluate temperature and water quality data, (4) assess prey species and food supply, (5) survey predator species more comprehensively than has been done in the past (6), and assess chinook salmon abundance and distribution (based on USFWS and District seining surveys. This reconnaissance would be used to develop hypotheses for future studies. The San Joaquin River monitoring should be a TRTAC or joint agency responsibility because of restoration efforts on other rivers.

The juvenile stranding/flow fluctuation study (proposal accepted by the TRTAC December 1997) would build on stranding and entrapment studies previously conducted by the Districts. Juvenile stranding has been documented by field surveys since 1987. These surveys focused on areas known, or suspected, to pose a high stranding risk. However, they did not completely assess stranding risk. The proposed program would: (1) catalogue sites surveyed in previous studies, (2) identify potential stranding sites from the existing GIS database, (3) identify slope, substrate, and entrapment area at various sites, (4) conduct surveys to document stranding and entrapment at a sample set of sites under various flow conditions (estimated 10 surveys, 2.5 days each over 2 years), (5) identify sites where highest stranding rates are likely to occur based on site conditions and observations, and (6) determine relative significance of stranding losses. These assessments will be used to: (a) develop a prioritized list of stranding sites to be addressed by channel or floodplain restoration or other methods, and (b) identify flow operations or other management actions to reduce stranding risks. These monitoring efforts are described by Ford (TID 1998) and summarized in the “Draft Proposal for Lower Tuolumne River Salmon Fry, Juvenile, and Smolt Distribution and Survival Monitoring” (TID 1997) distributed to the TRTAC in December 1997. Detailed descriptions of the studies and their findings can be found in reports submitted to FERC by the TID/MID.

5.3.4. Summary

Adaptive management is essential to successful implementation of the Restoration Plan. Adaptive management will not only improve management policy and restoration actions, but also will extend our knowledge of the river ecosystems. These are ambitious goals for any program, but much more so for a program attempting large-scale ecological restoration of a river the size of the Tuolumne River. Add the socioeconomic uncertainties, and the task of restoring the river becomes daunting.

But this acknowledgement does not justify inaction, and the stakeholders involved in the implementation of this Restoration Plan must be willing to accept slow progress, investment of substantial amounts of time and money, and the risks involved in decision making. We must acknowledge the inherent uncertainty of our actions, weigh possible outcomes with considerable caution, then proceed with the best science available.

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APPENDICES

Appendix A. Tuolumne River at La Grange annual hydrographs
Appendix B. Tuolumne River series lists, species lists, and riparian inventory map

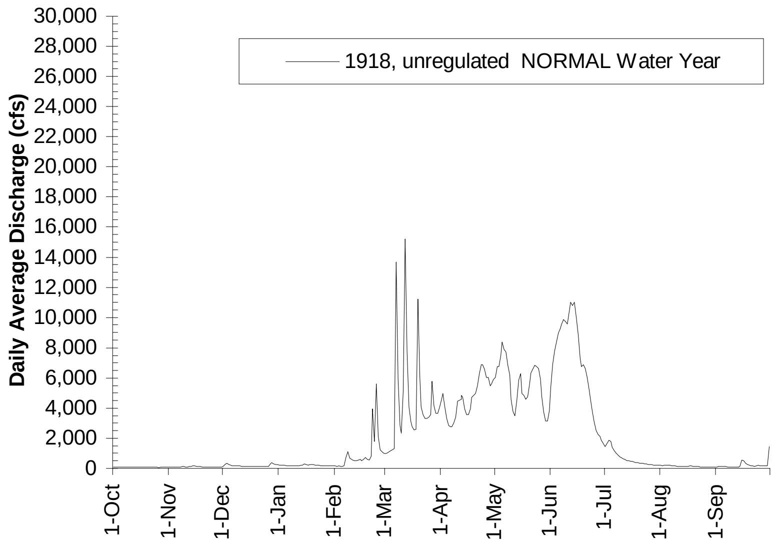
APPENDIX A

ANNUAL HYDROGRAPHS FOR THE TUOLUMNE RIVER AT LA GRANGE

USGS GAGING STATION 11-289650

WATER YEAR 1918 - 1997

APPENDIX A


1918, unregulated NORMAL Water Year
Daily Average Discharge (cfs)
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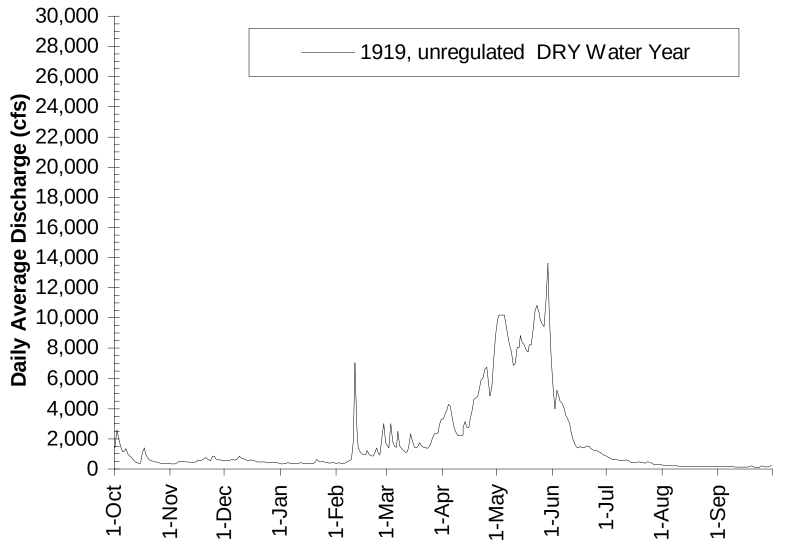
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1919, unregulated DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
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1-Dec
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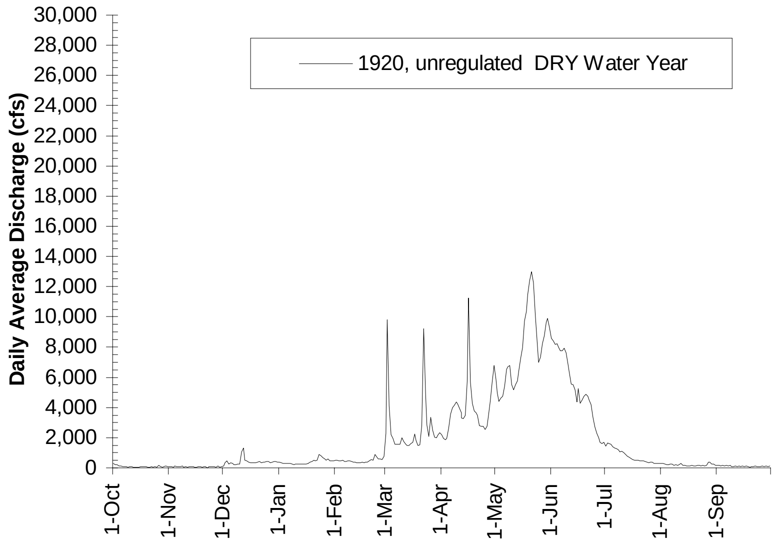
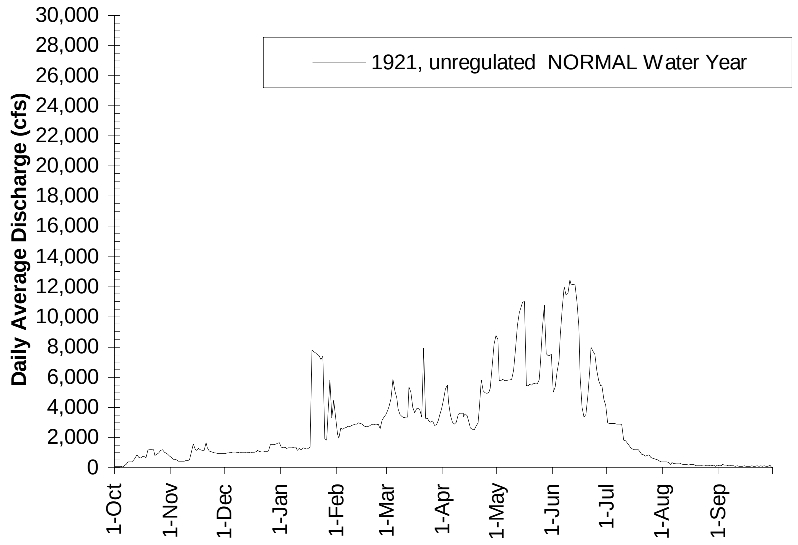
1-Jul
1-Aug
1-Sep


1920, unregulated DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1921, unregulated NORMAL Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
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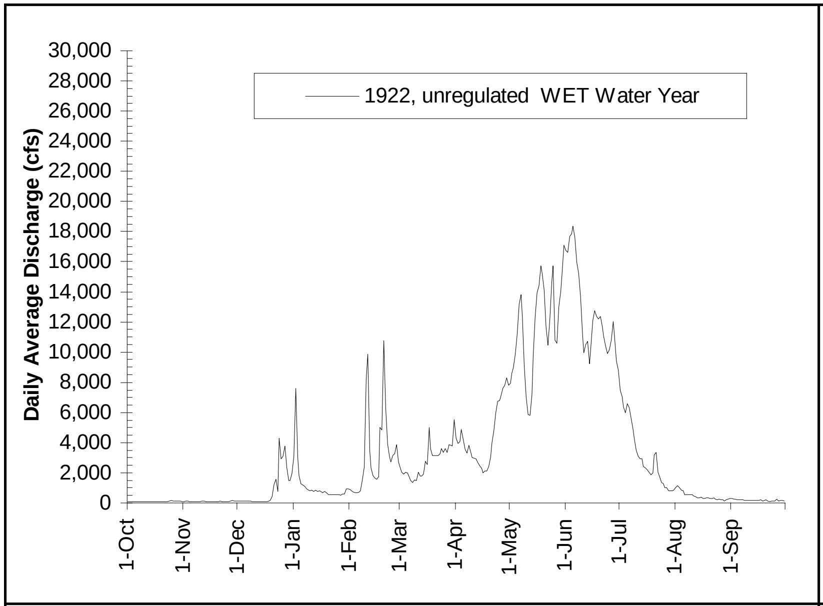
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1922, unregulated WET Water Year
Daily Average Discharge (cfs)
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28,000
26,000
24,000
22,000
20,000
18,000
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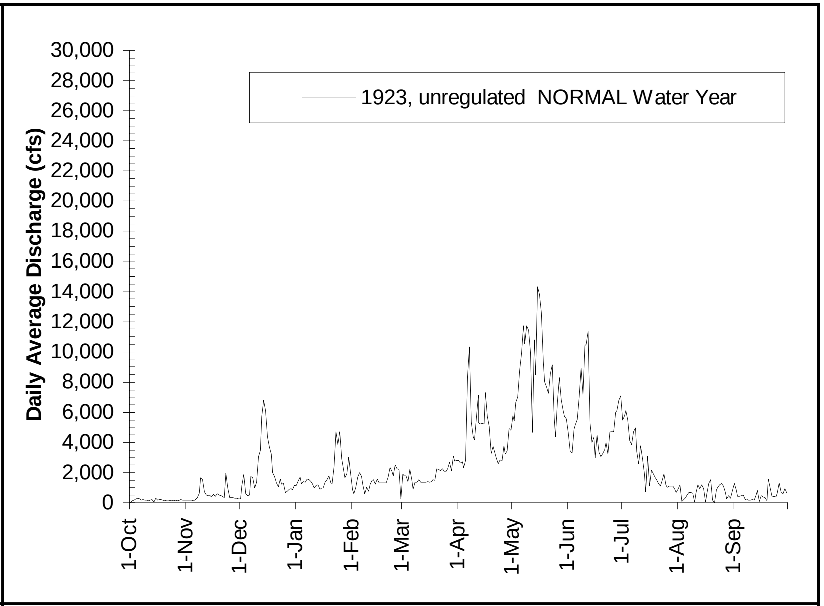
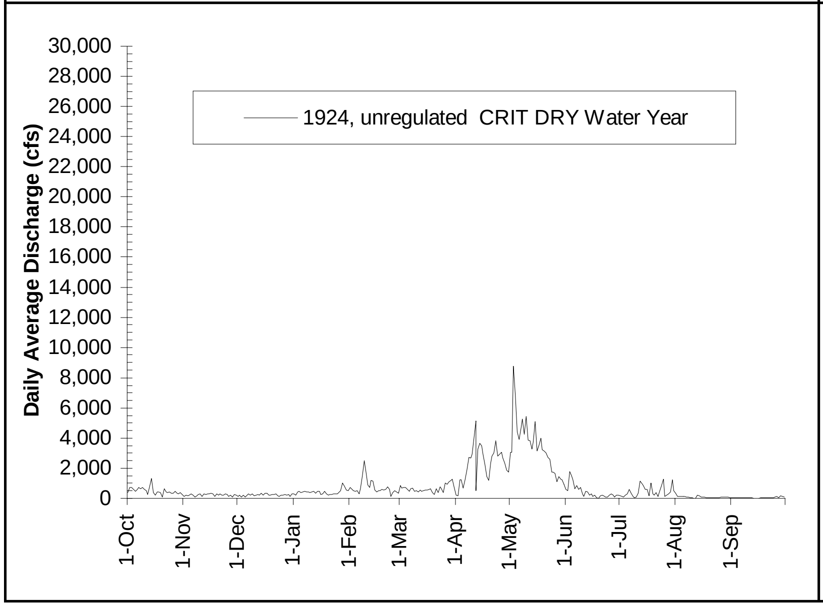
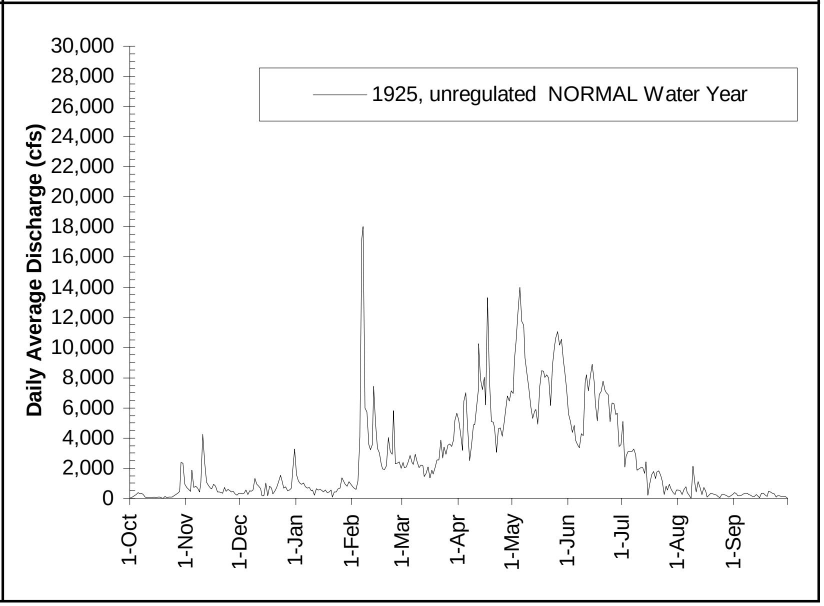
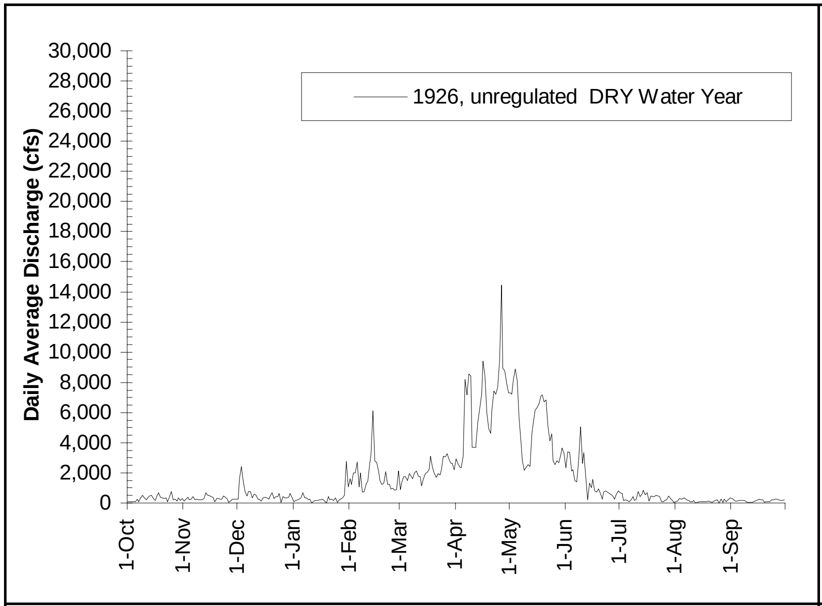
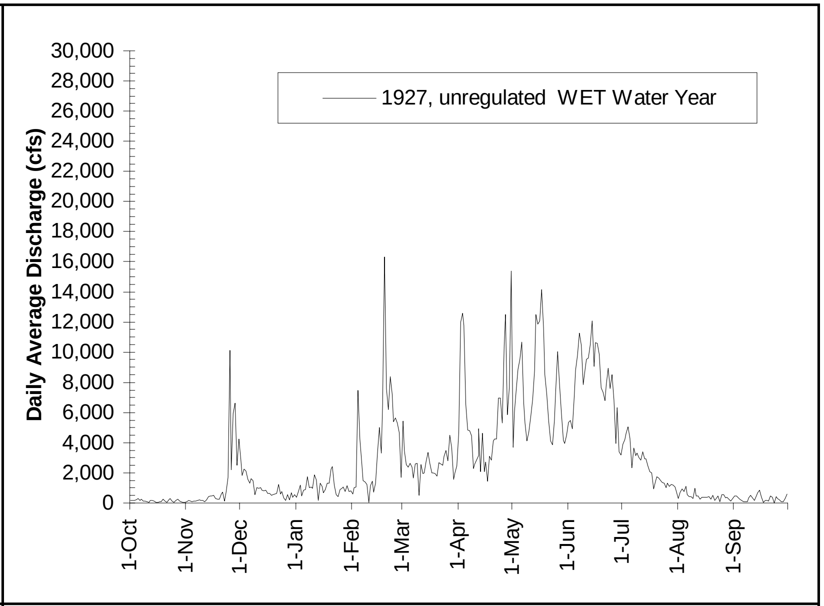
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep

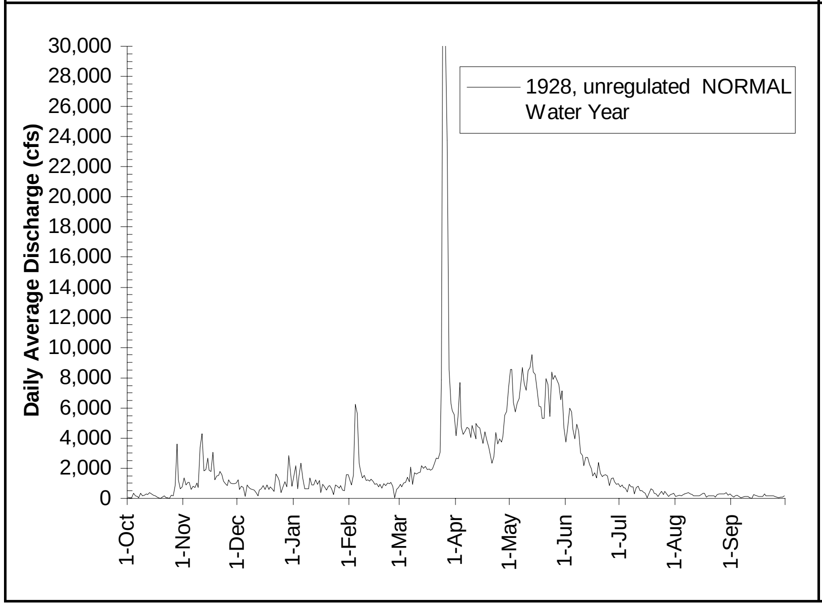

1923, unregulated NORMAL Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep

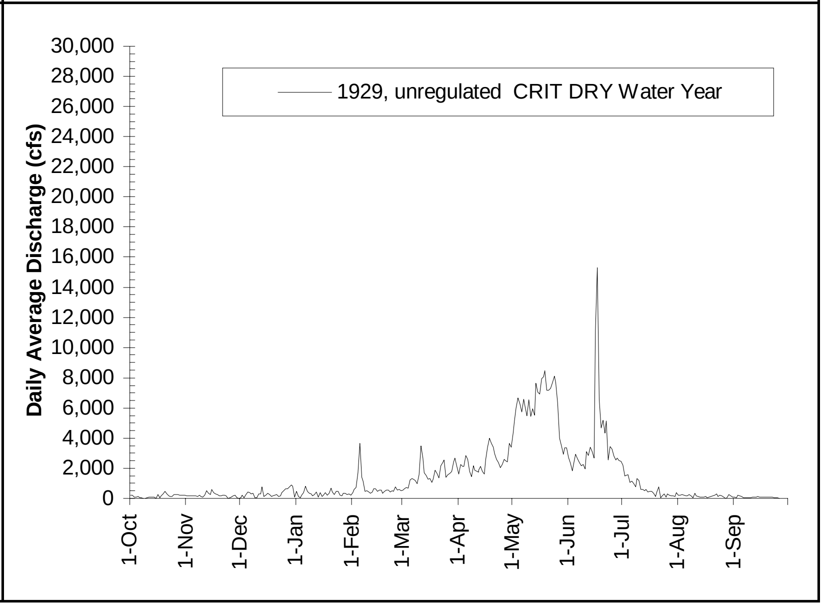

1924, unregulated CRIT DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep

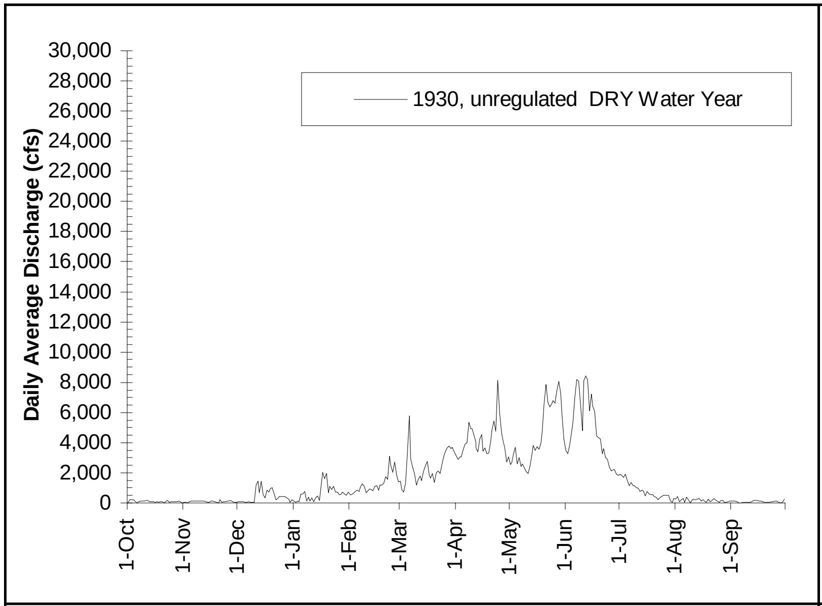

1925, unregulated NORMAL Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep

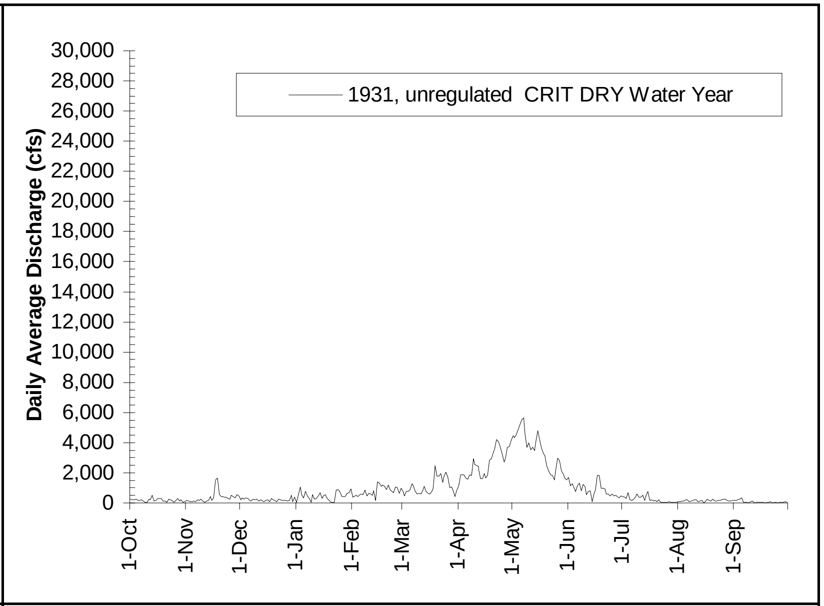

1926, unregulated DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep

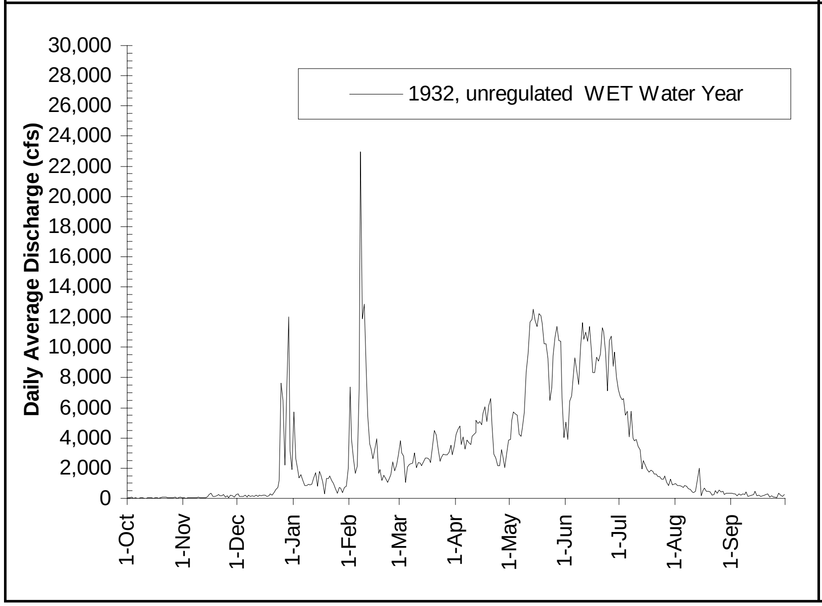

1927, unregulated WET Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1928, unregulated NORMAL Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1929, unregulated CRIT DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1930, unregulated DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1931, unregulated CRIT DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1932, unregulated WET Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
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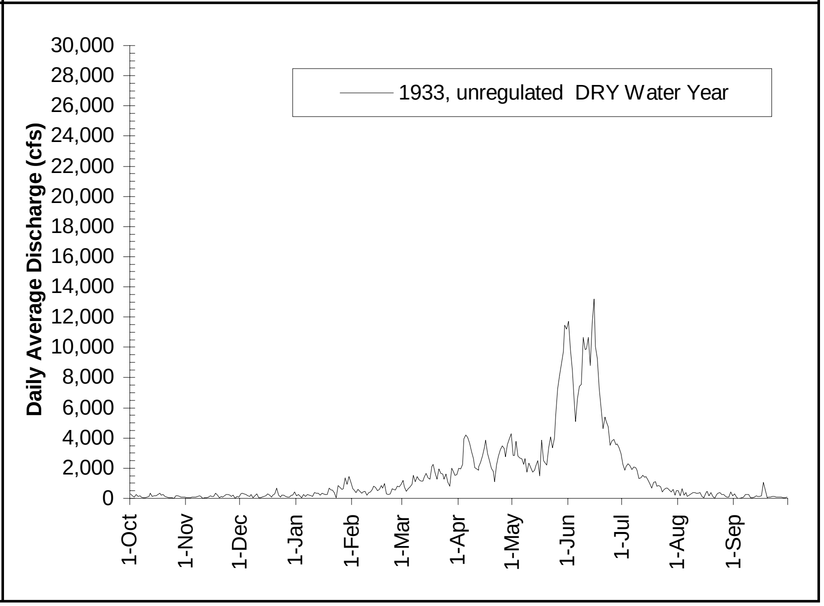
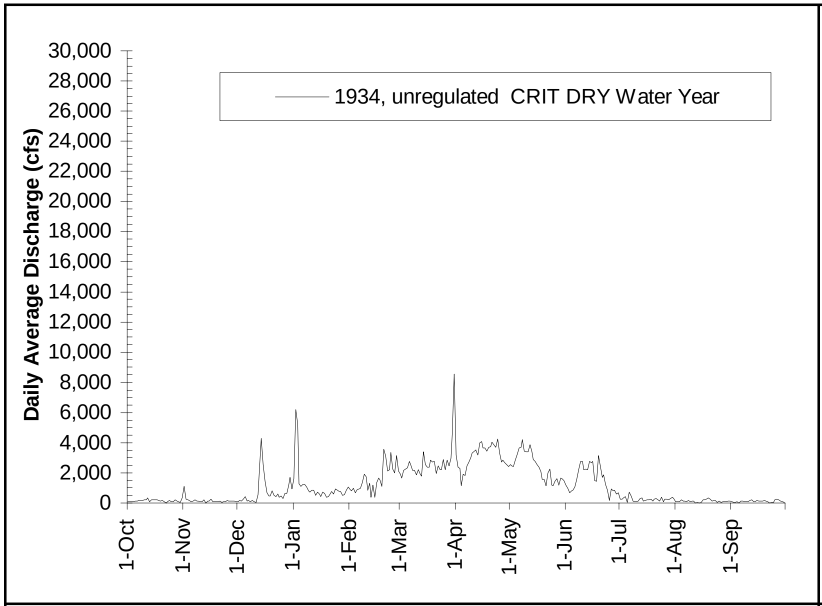
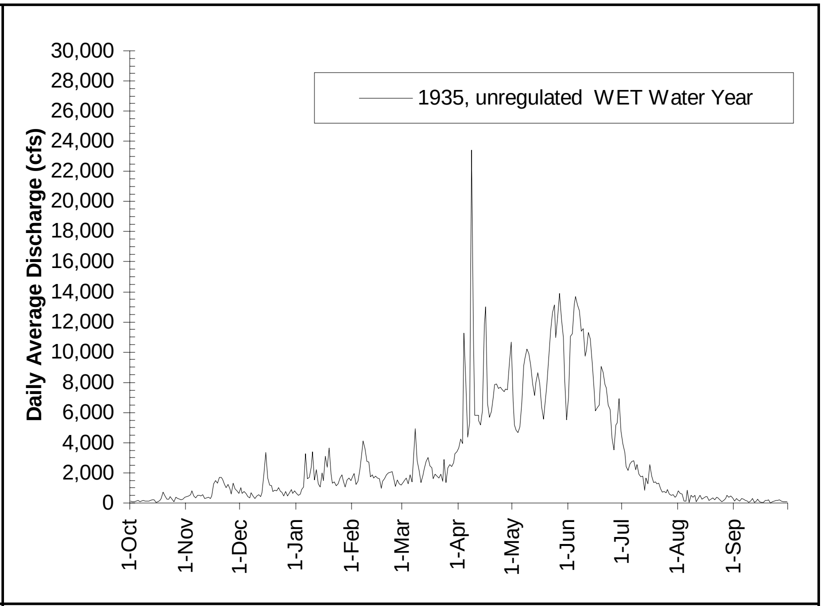
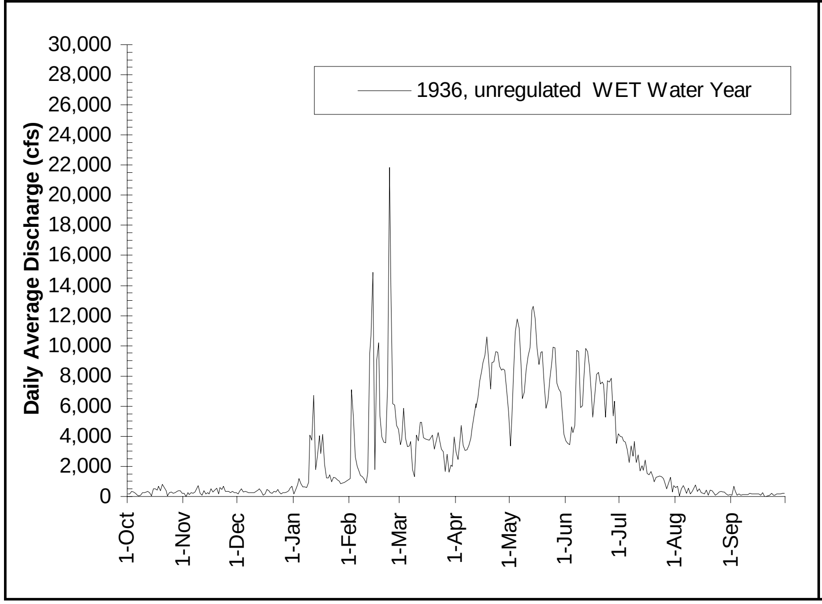
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1933, unregulated DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1934, unregulated CRIT DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1935, unregulated WET Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1936, unregulated WET Water Year
Daily Average Discharge (cfs)
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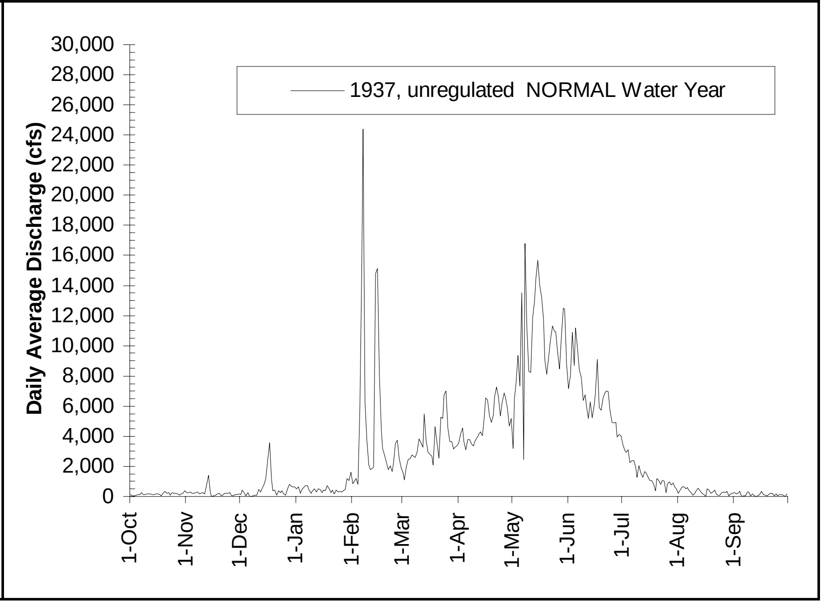
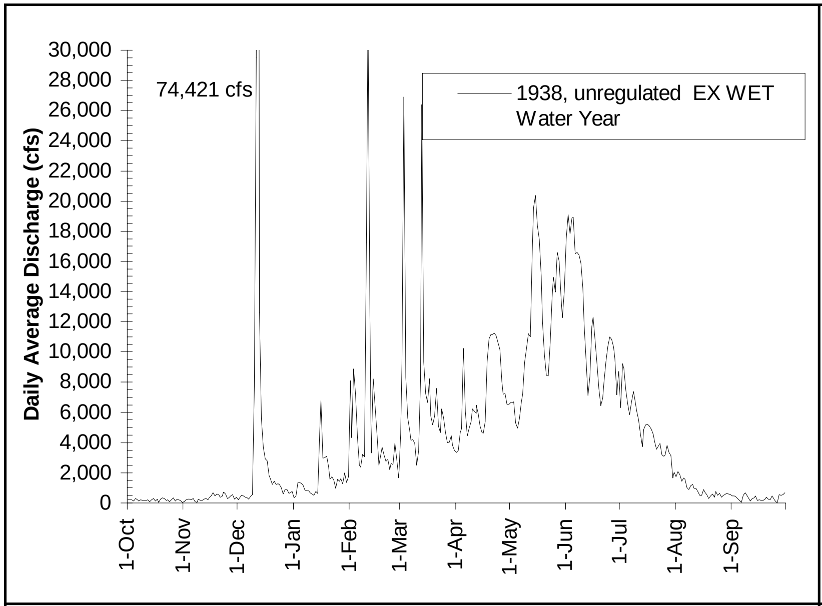
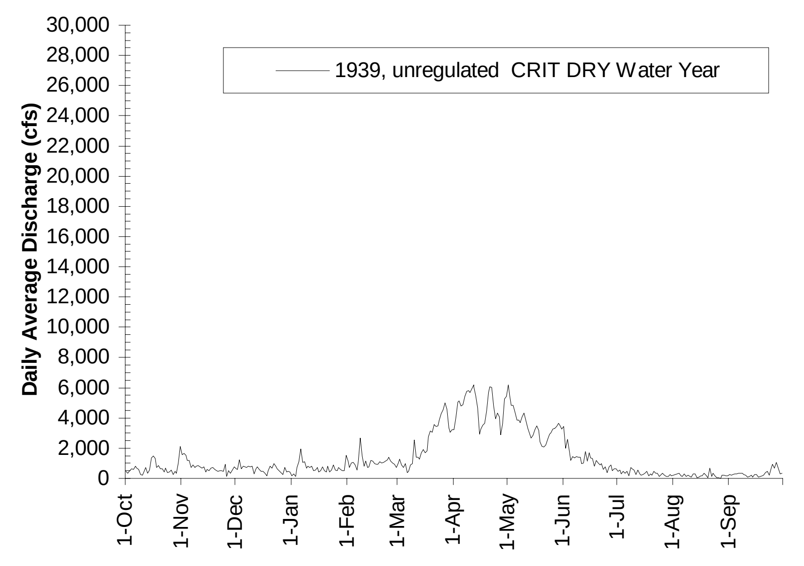
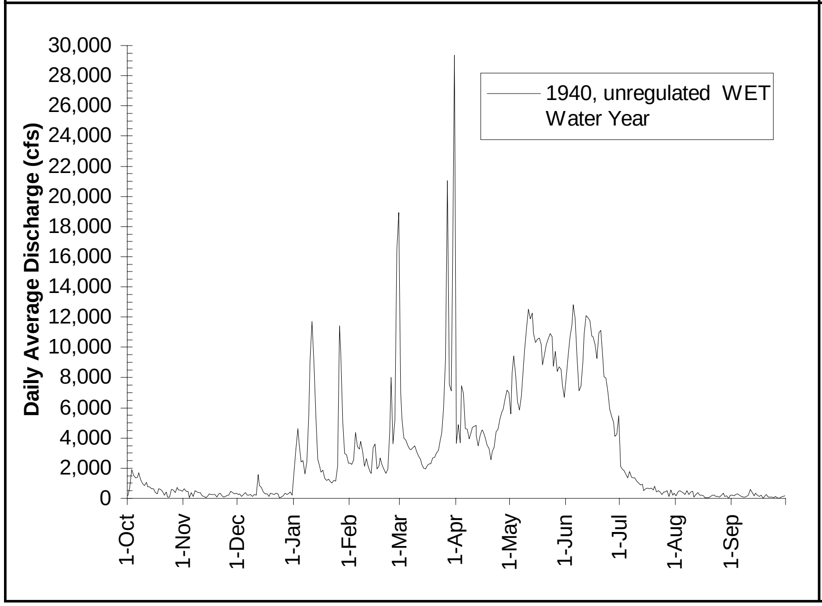
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1937, unregulated NORMAL Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
74,421 cfs
1938, unregulated EX WET Water Year
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1939, unregulated CRIT DRY Water Year
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


Daily Average Discharge (cfs)
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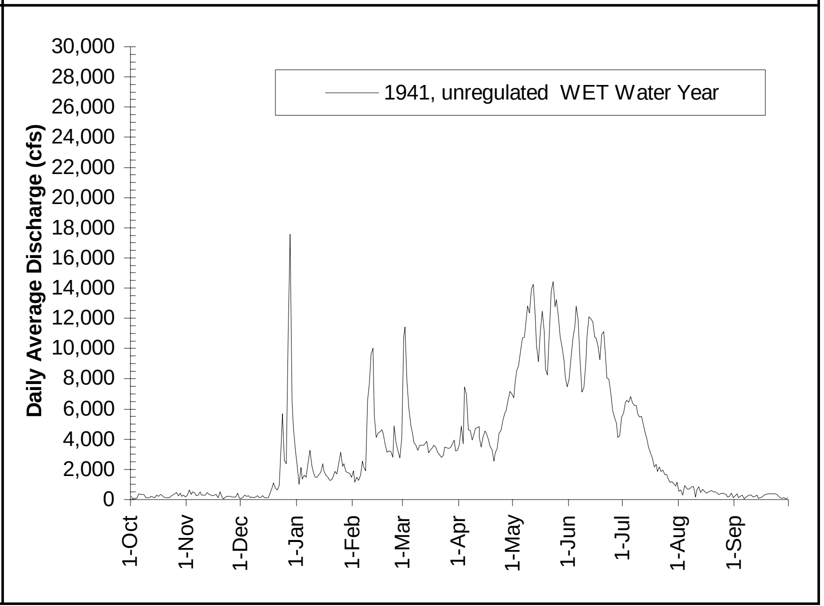
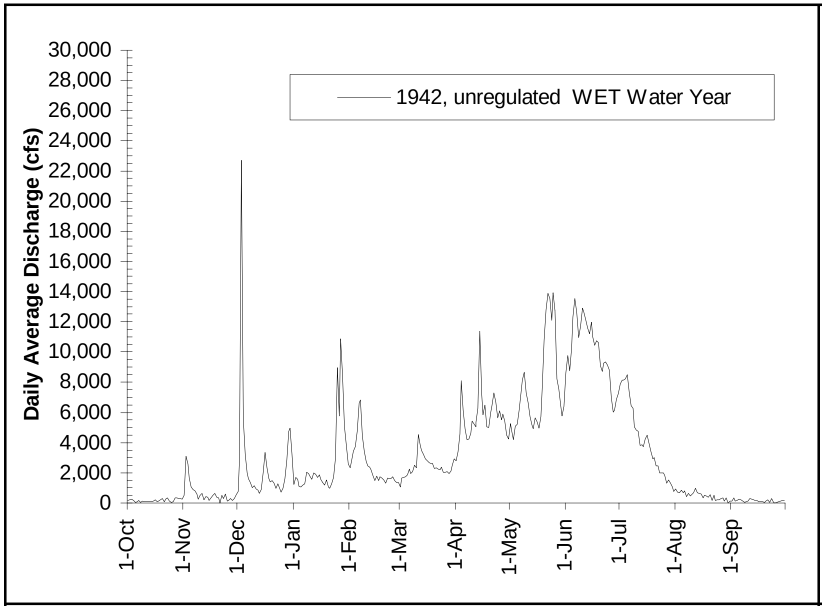
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1940, unregulated WET Water Year
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1941, unregulated WET Water Year
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1942, unregulated WET Water Year
Daily Average Discharge (cfs)
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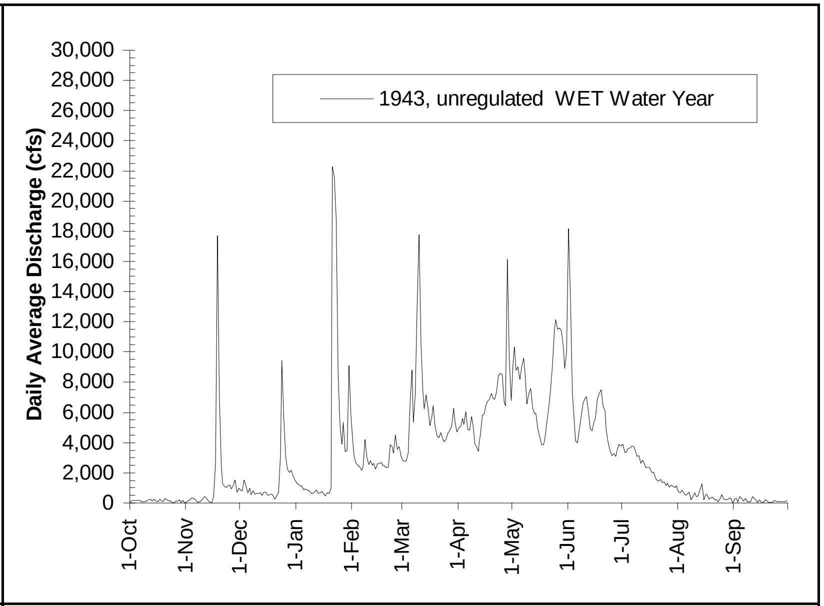
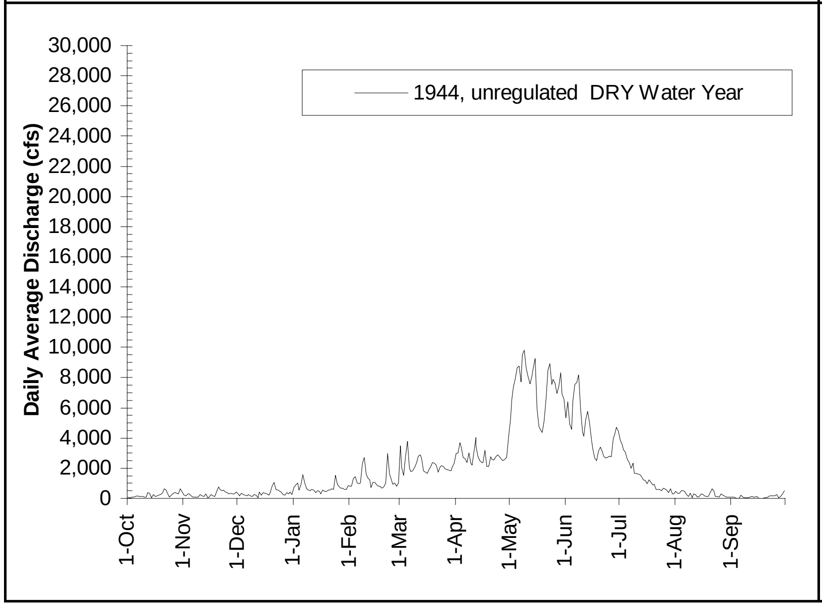
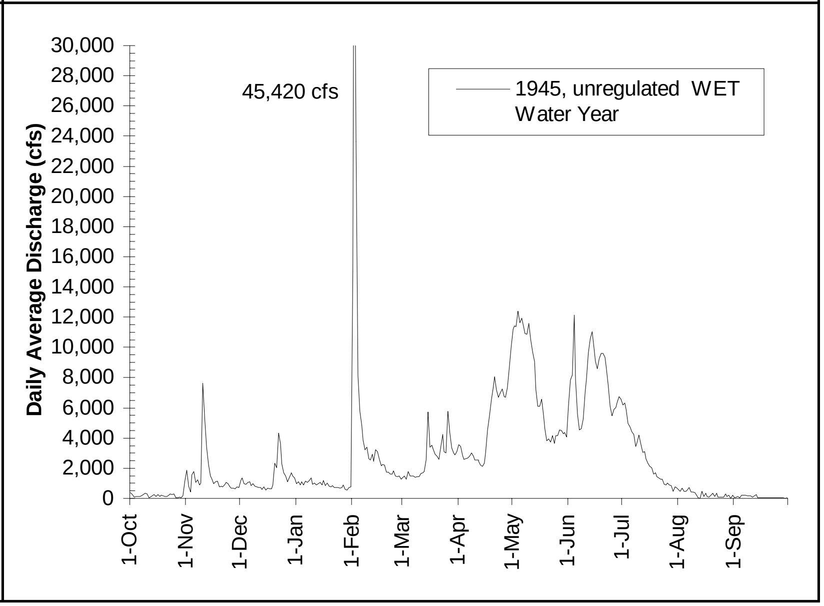
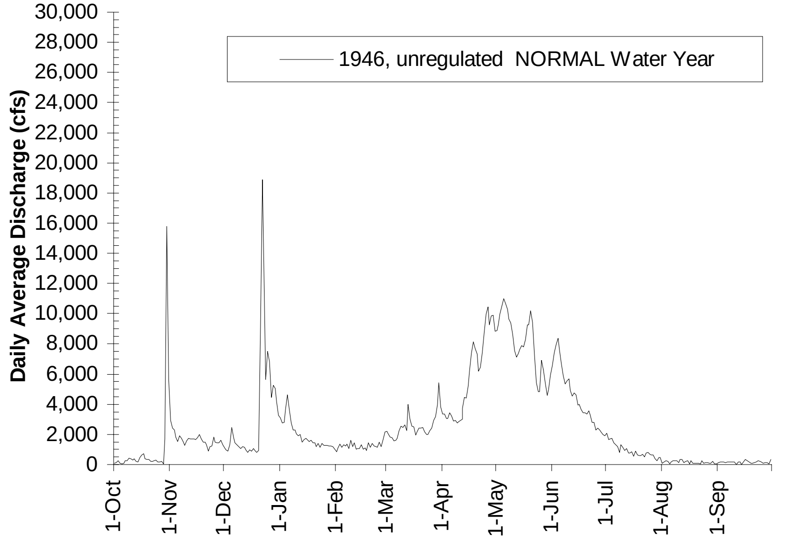
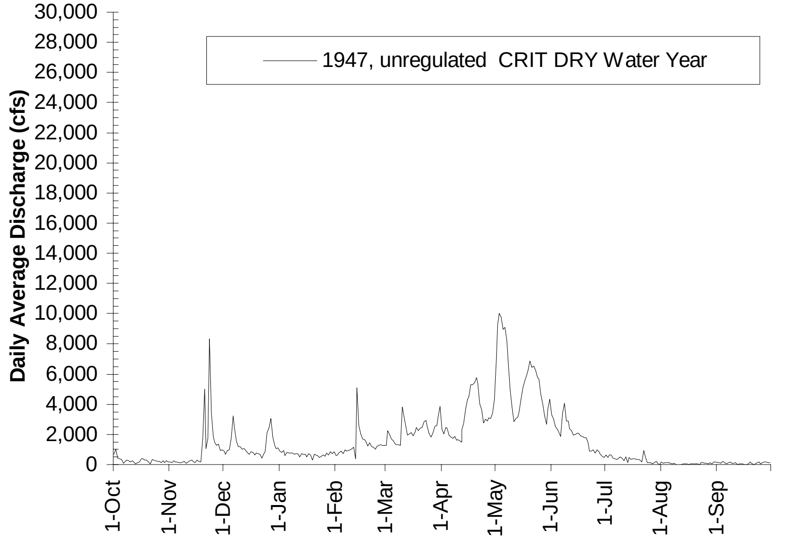
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep

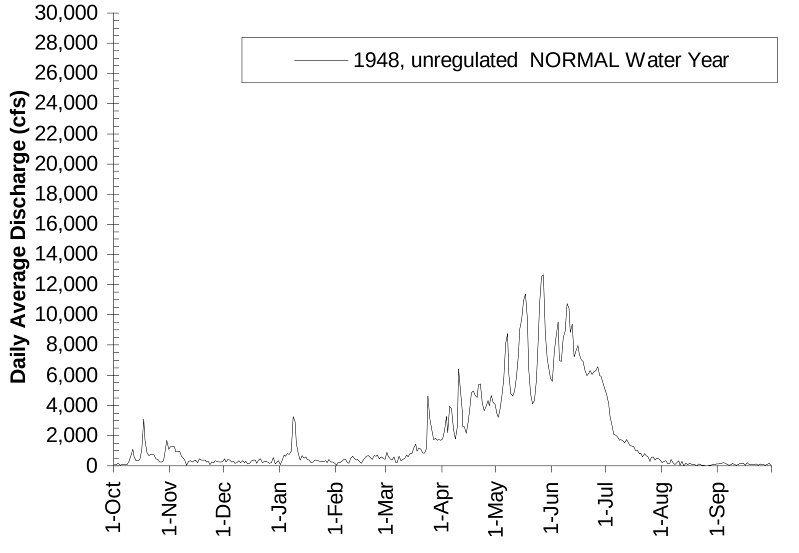

1943, unregulated WET Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep

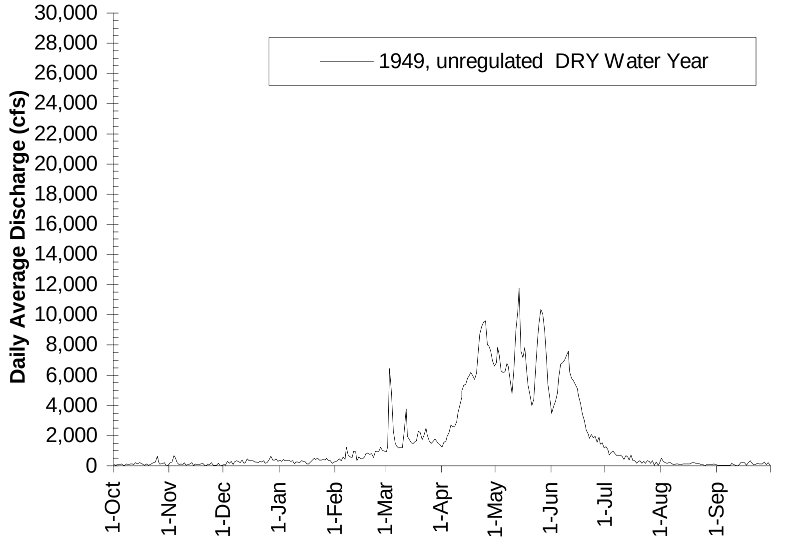

1944, unregulated DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep

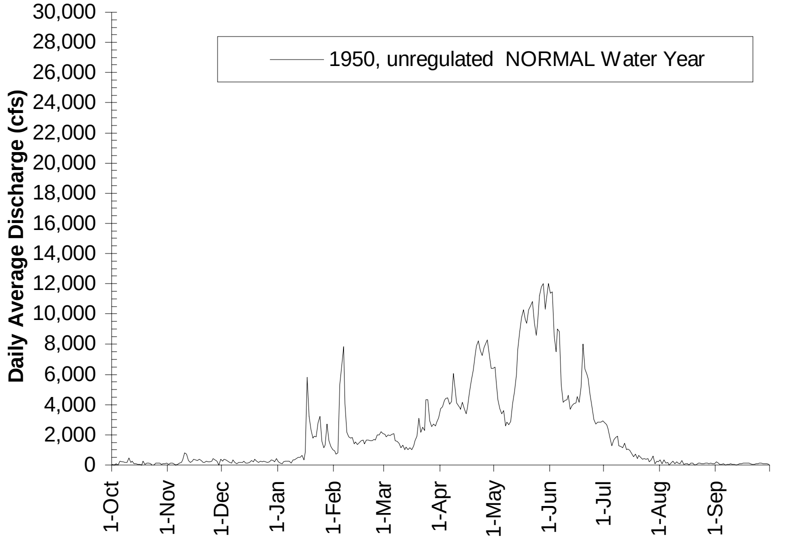

45,420 cfs
1945, unregulated WET Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1946, unregulated NORMAL Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1947, unregulated CRIT DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1948, unregulated NORMAL Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1949, unregulated DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1950, unregulated NORMAL Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
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1-May
1-Jun
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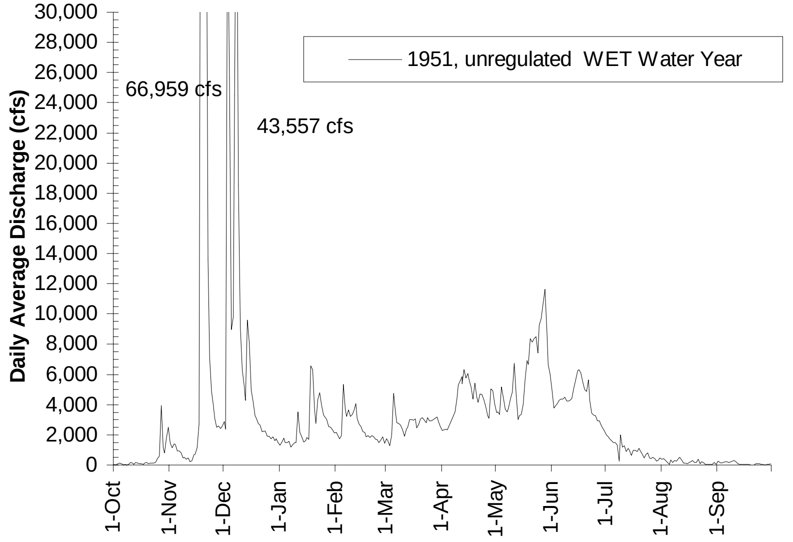
1-Aug
1-Sep


1951, unregulated WET Water Year
66,959 cfs
43,557 cfs
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
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1-May
1-Jun
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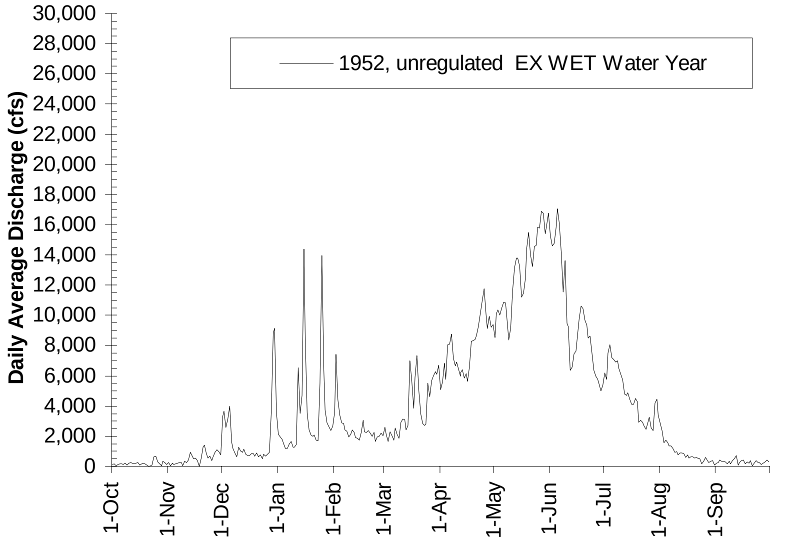
1-Aug
1-Sep


1952, unregulated EX WET Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
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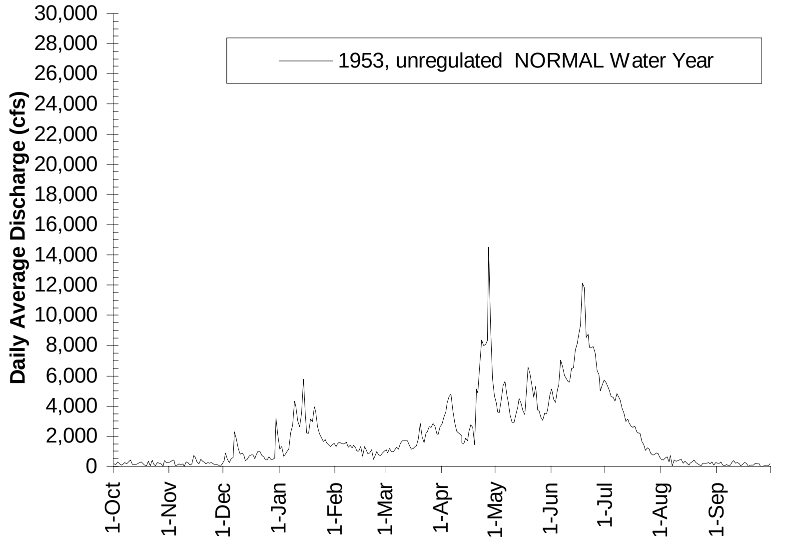
1-Jun
1-Jul
1-Aug
1-Sep


1953, unregulated NORMAL Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
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1-May
1-Jun
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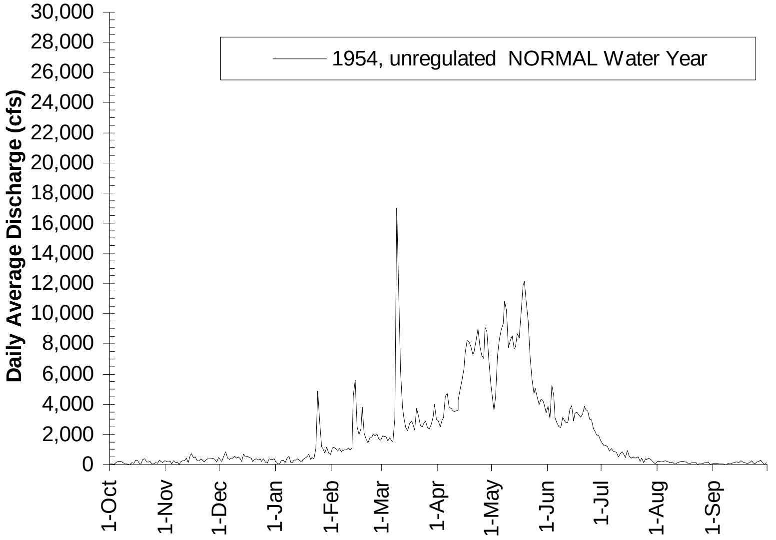
1-Sep


1954, unregulated NORMAL Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
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1-Jan
1-Feb
1-Mar
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1-May
1-Jun
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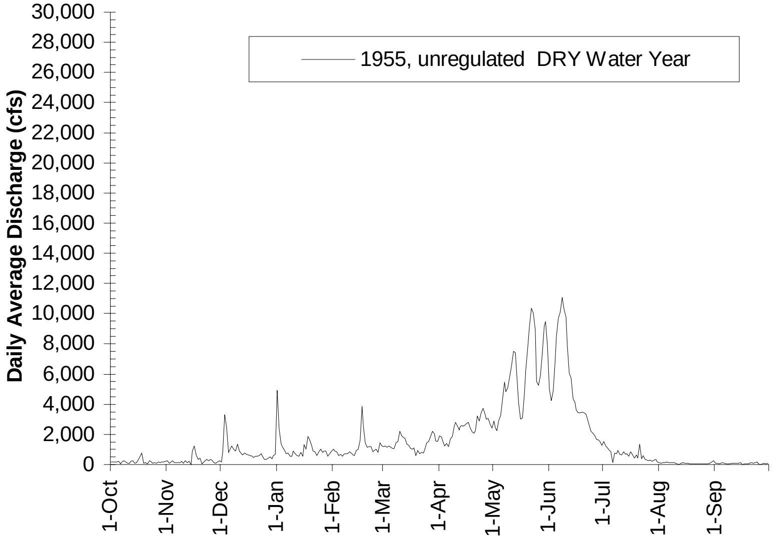
1-Sep


1955, unregulated DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
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1-Jan
1-Feb
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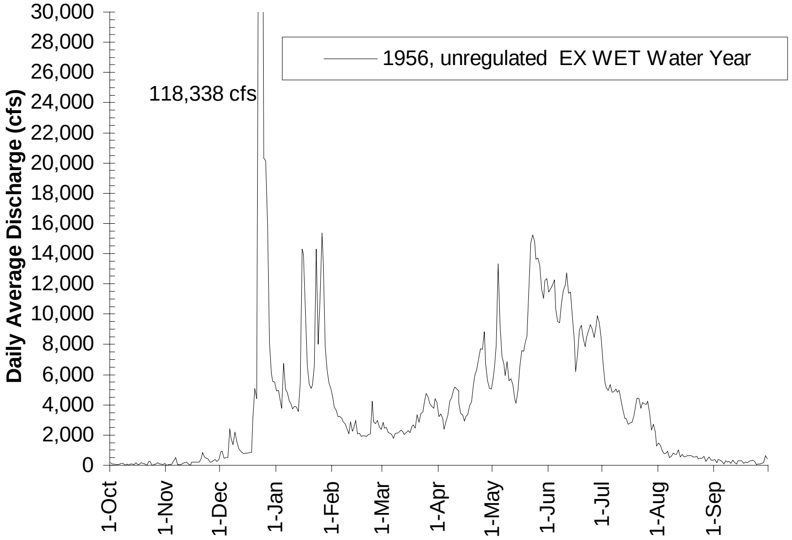
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1956, unregulated EX WET Water Year
118,338 cfs
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
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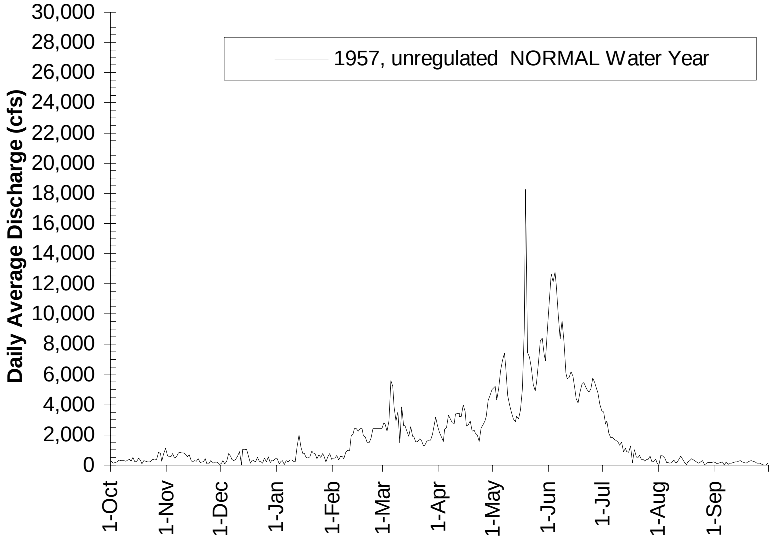
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1957, unregulated NORMAL Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
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1-Jan
1-Feb
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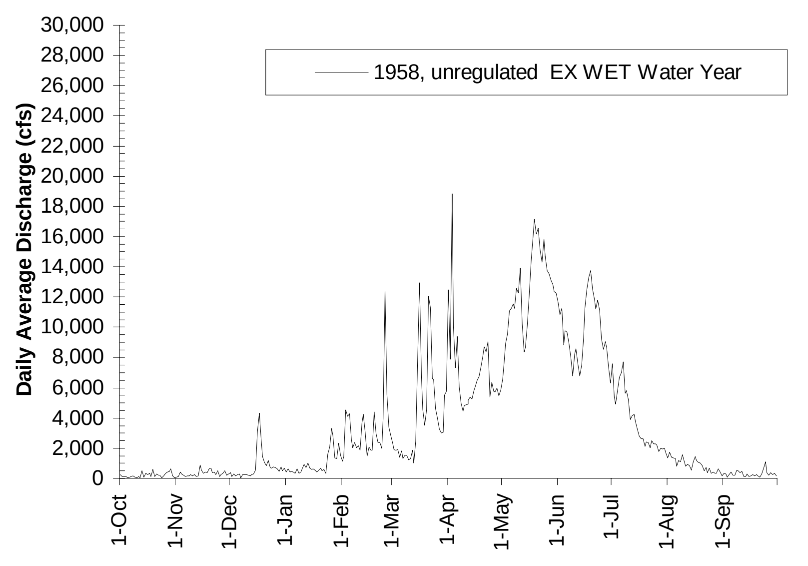
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1958, unregulated EX WET Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
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1-Jan
1-Feb
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1-May
1-Jun
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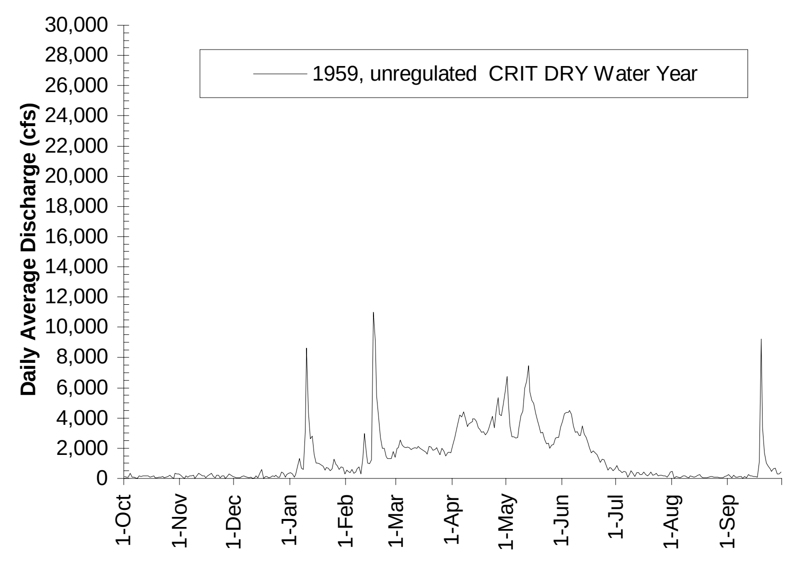
1-Aug
1-Sep


1959, unregulated CRIT DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
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1-Dec
1-Jan
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1-Mar
1-Apr
1-May
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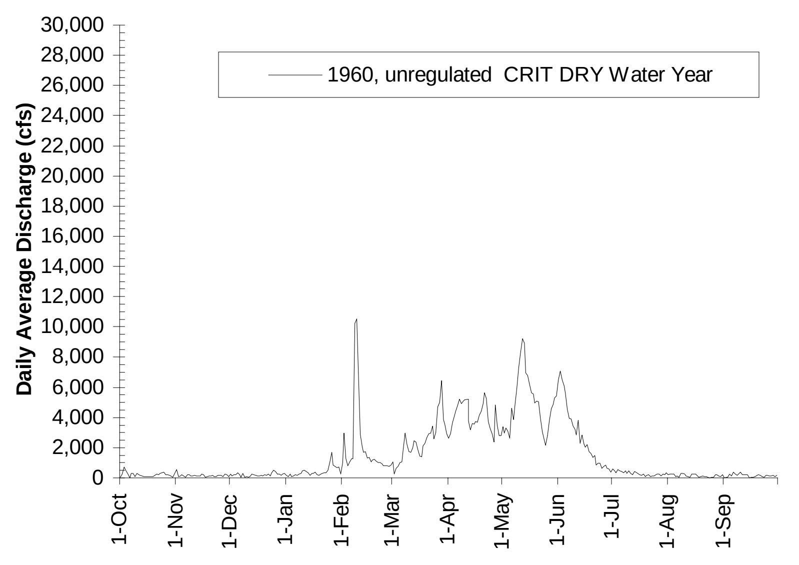
1-Jul
1-Aug
1-Sep


1960, unregulated CRIT DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
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1-Jan
1-Feb
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1-May
1-Jun
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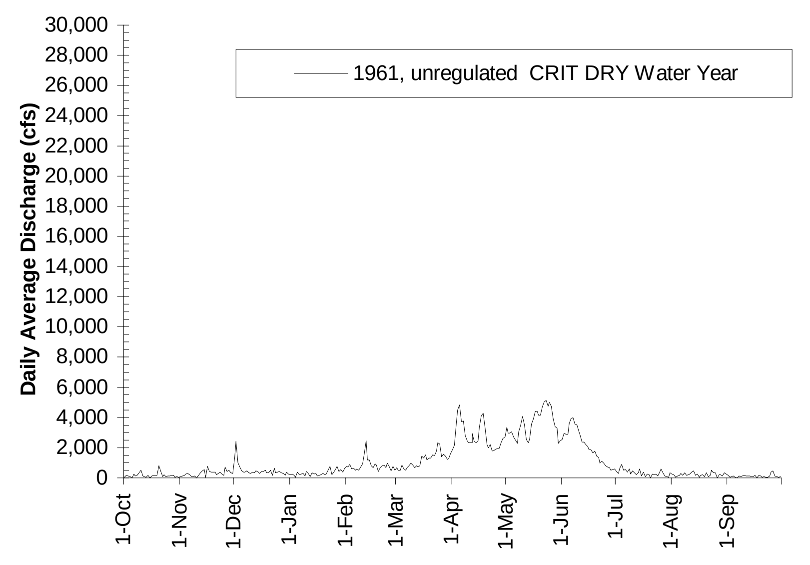
1-Aug
1-Sep


1961, unregulated CRIT DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
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1-Feb
1-Mar
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1-May
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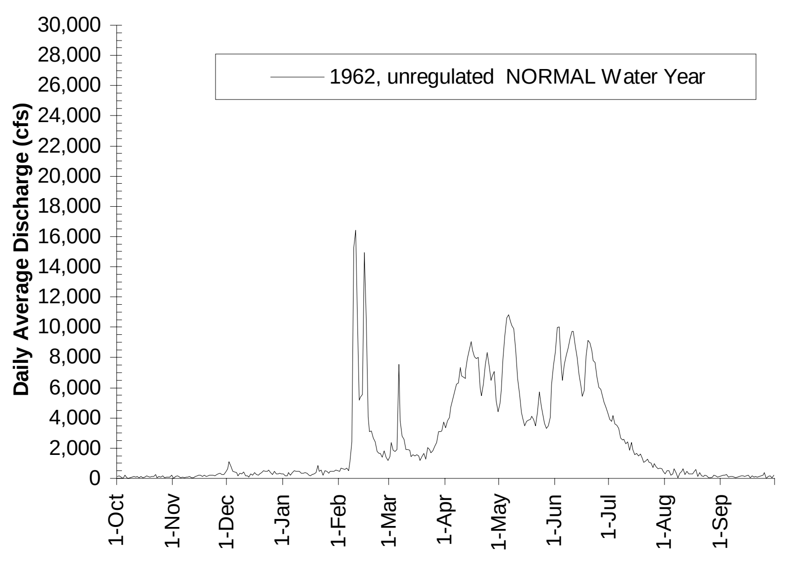
1-Aug
1-Sep



1962, unregulated NORMAL Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
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1-Feb
1-Mar
1-Apr
1-May
1-Jun
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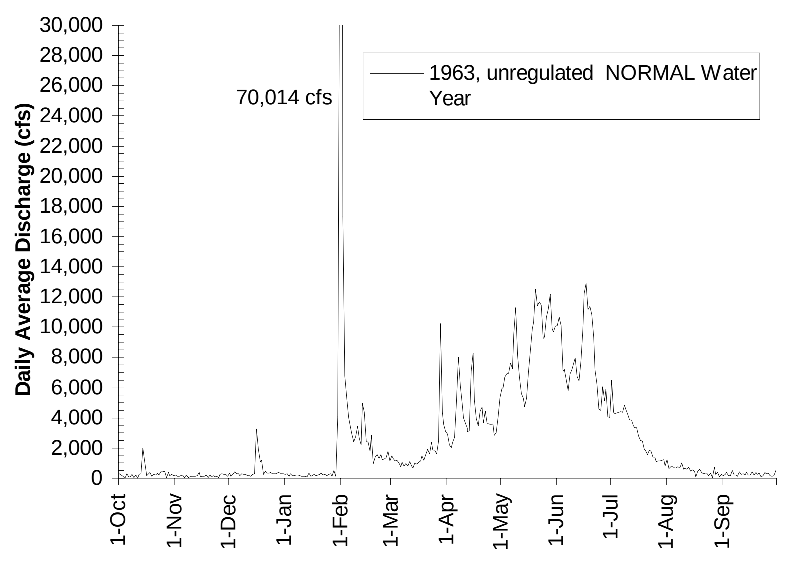
1-Aug
1-Sep



1963, unregulated NORMAL Water Year
70,014 cfs
Daily Average Discharge (cfs)
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28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
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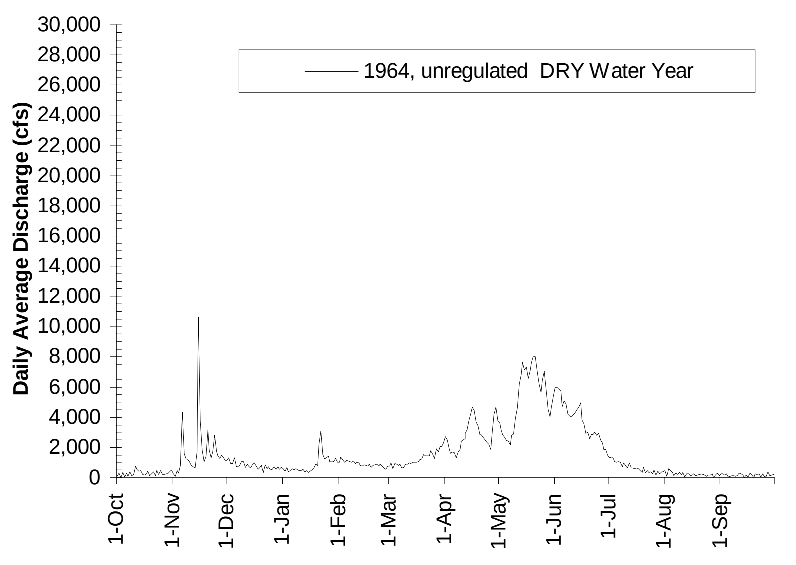
1-Sep



1964, unregulated DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
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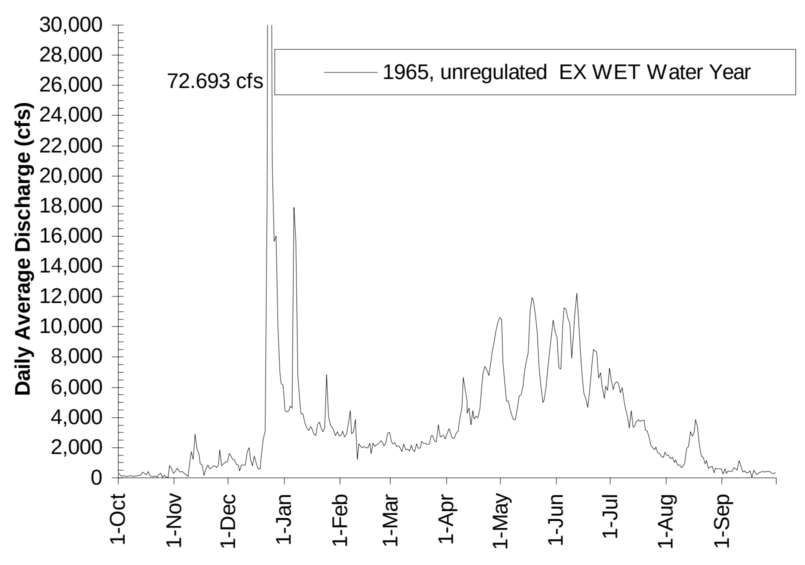
1-Aug
1-Sep



1965, unregulated EX WET Water Year
72.693 cfs
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
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1-May
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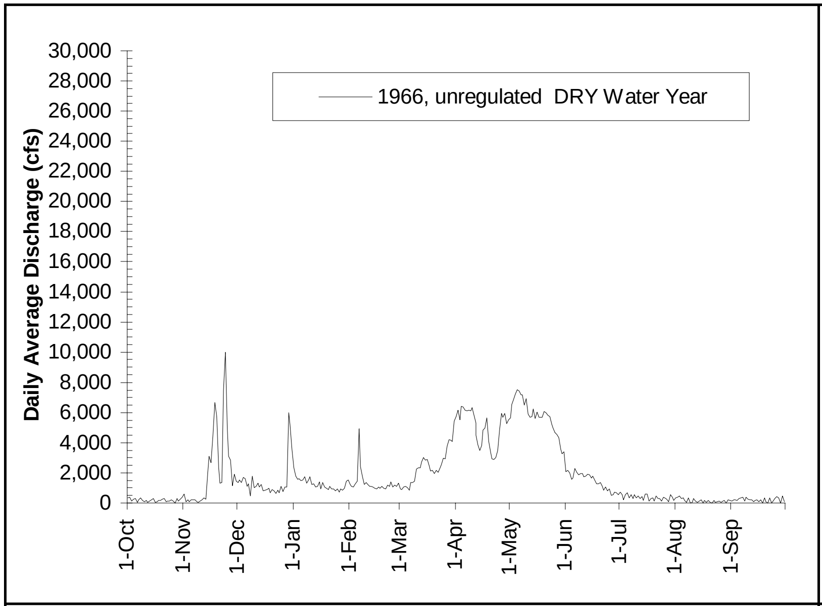
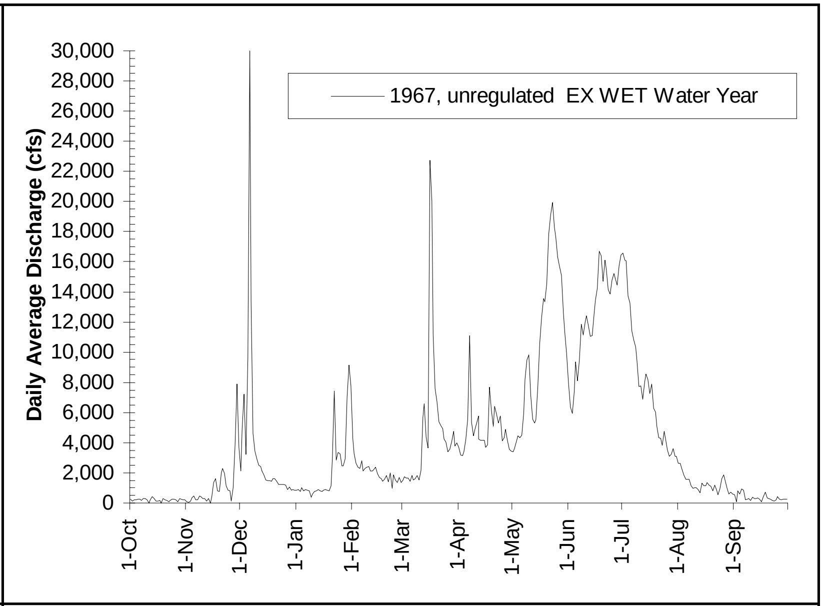
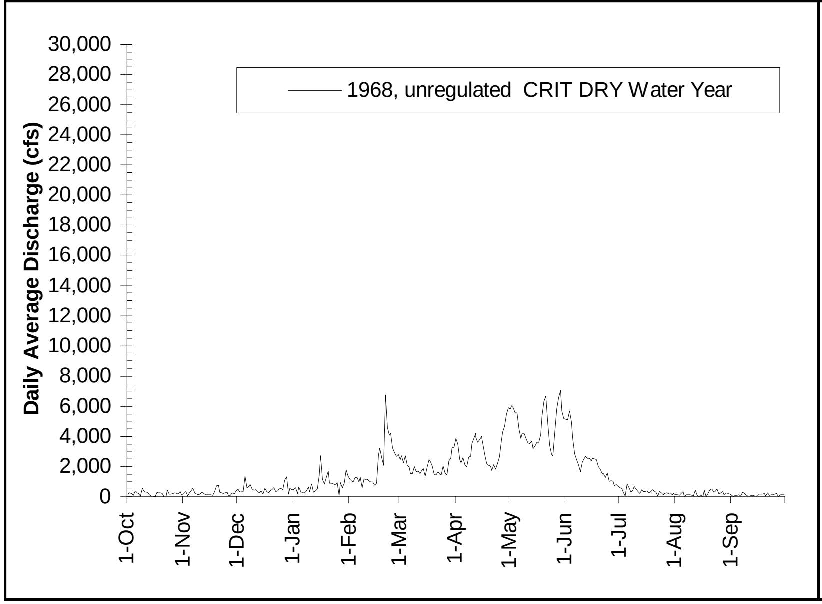
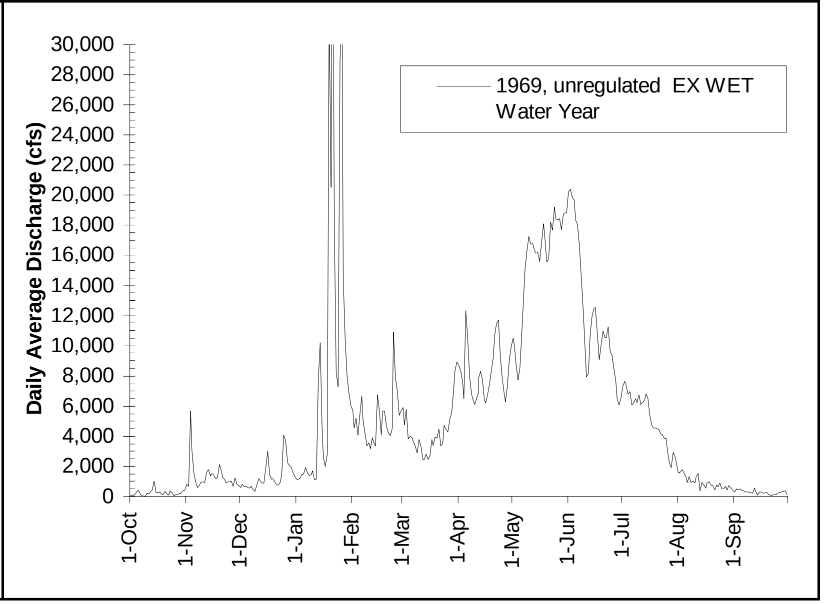
1-Aug
1-Sep


1966, unregulated DRY Water Year
Daily Average Discharge (cfs)
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
22,000
24,000
26,000
28,000
30,000
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1967, unregulated EX WET Water Year
Daily Average Discharge (cfs)
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
22,000
24,000
26,000
28,000
30,000
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1968, unregulated CRIT DRY Water Year
Daily Average Discharge (cfs)
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
22,000
24,000
26,000
28,000
30,000
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


1969, unregulated EX WET Water Year
Daily Average Discharge (cfs)
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
22,000
24,000
26,000
28,000
30,000
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
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1-Apr
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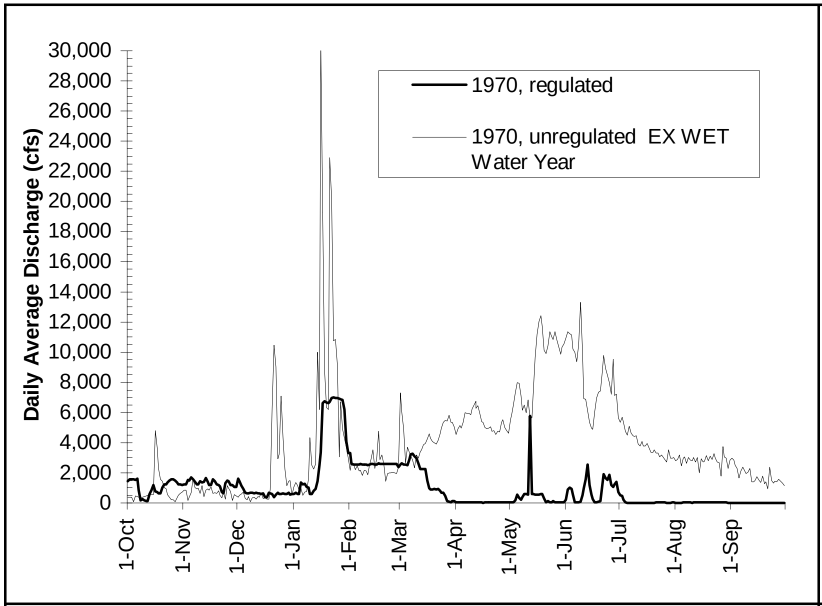
1-Sep


1970, regulated
1970, unregulated EX WET Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
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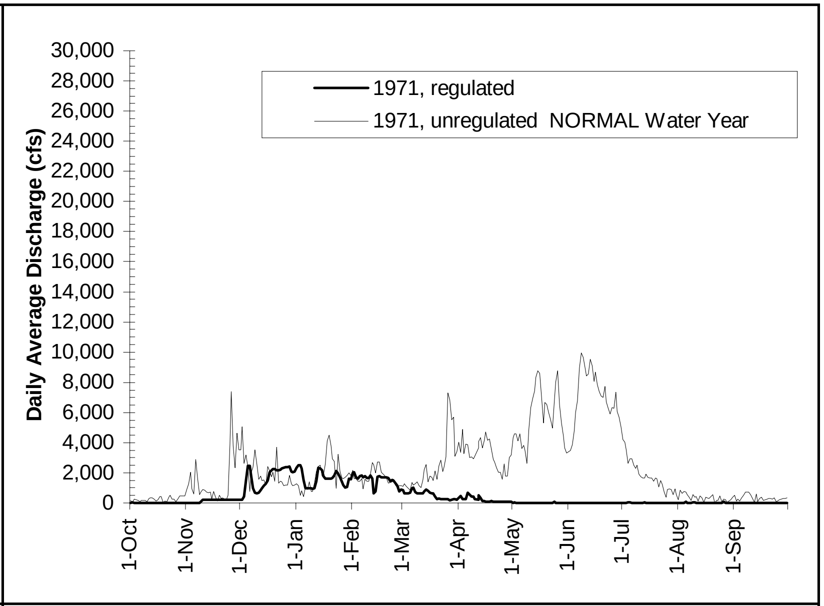
1-Sep


1971, regulated
1971, unregulated NORMAL Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
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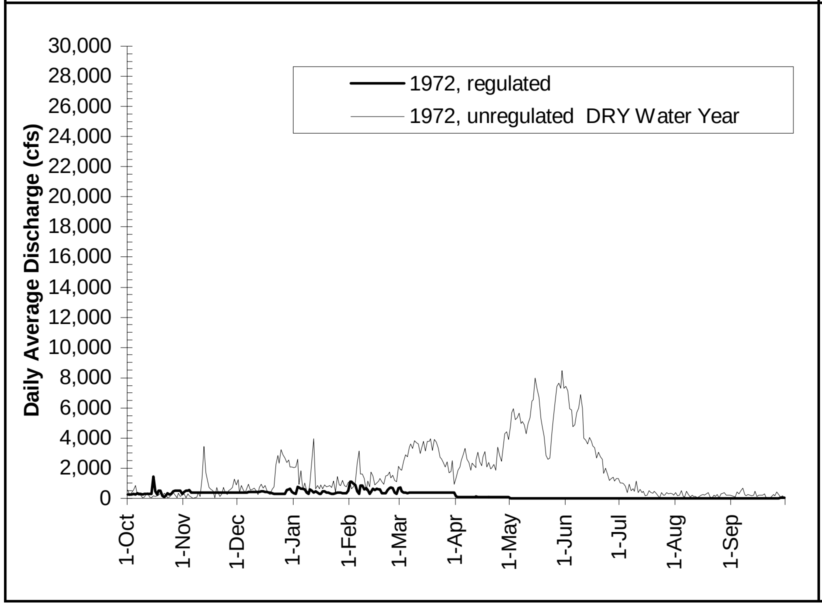
1-Sep


1972, regulated
1972, unregulated DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
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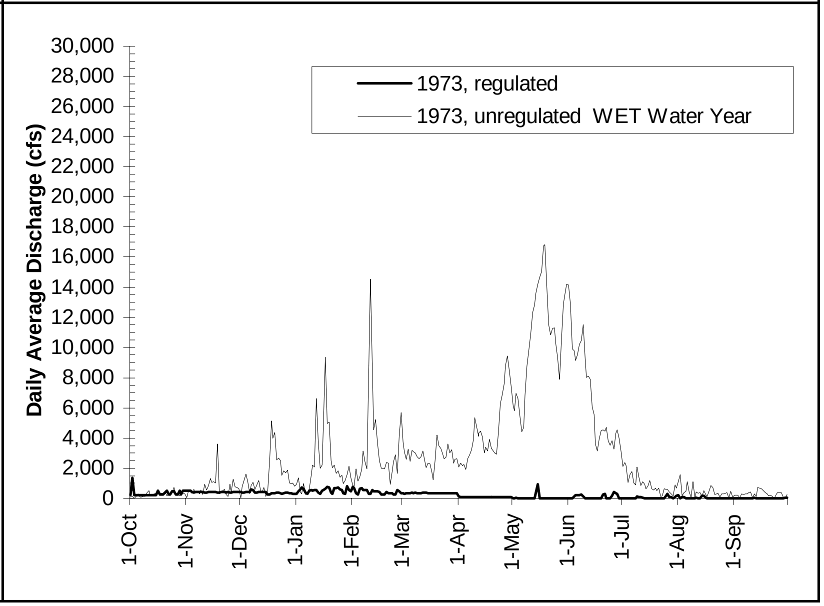
1-Sep


1973, regulated
1973, unregulated WET Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
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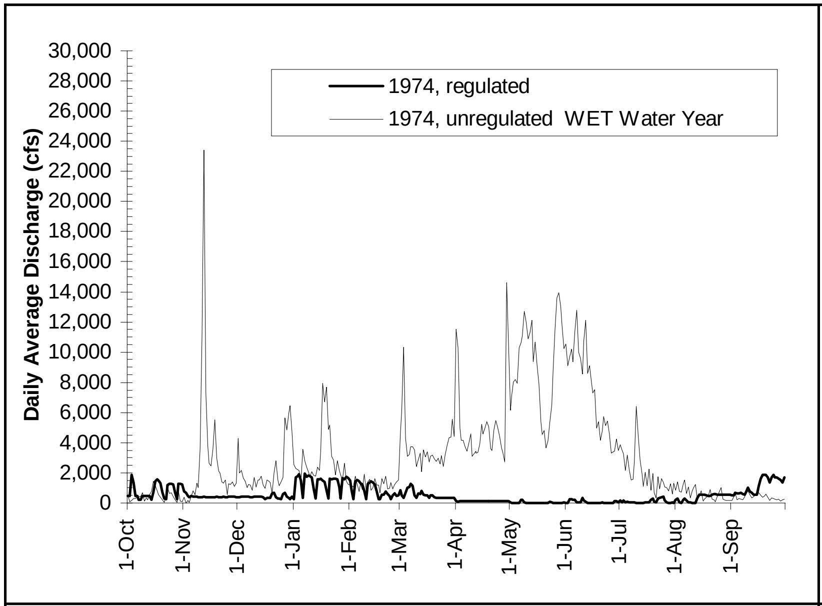
1-Aug
1-Sep


1974, regulated
1974, unregulated WET Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
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1-Jan
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1-May
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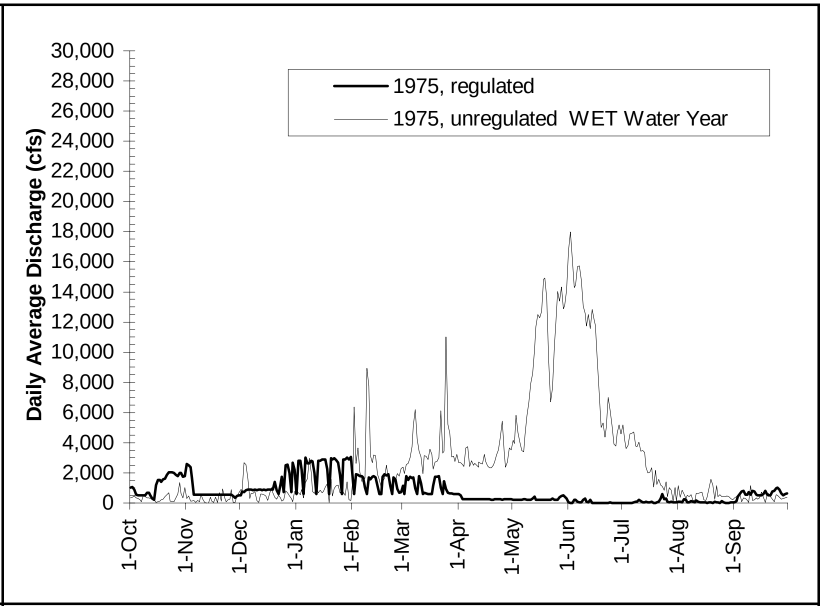
1-Aug
1-Sep


1975, regulated
1975, unregulated WET Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
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1-Oct
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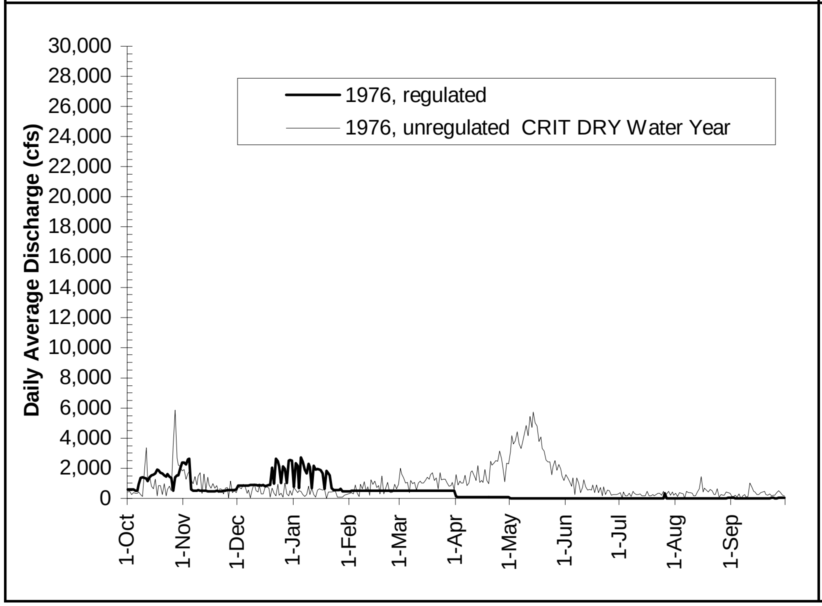
1-Sep


1976, regulated
1976, unregulated CRIT DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
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1-Feb
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1-May
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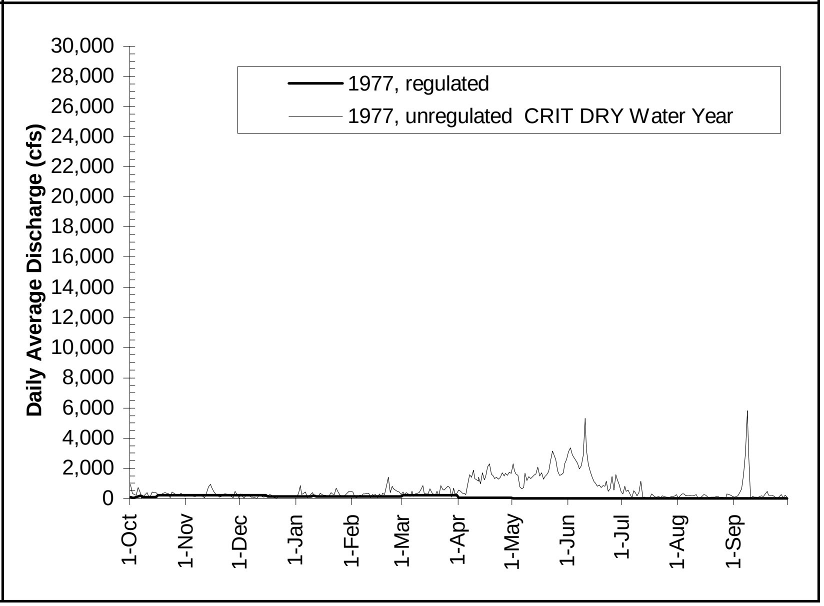
1-Aug
1-Sep


1977, regulated
1977, unregulated CRIT DRY Water Year
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
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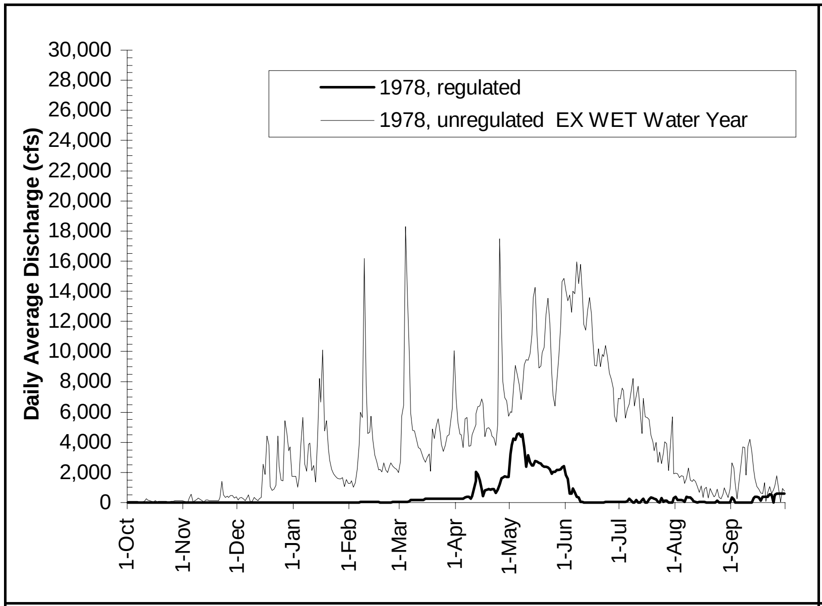
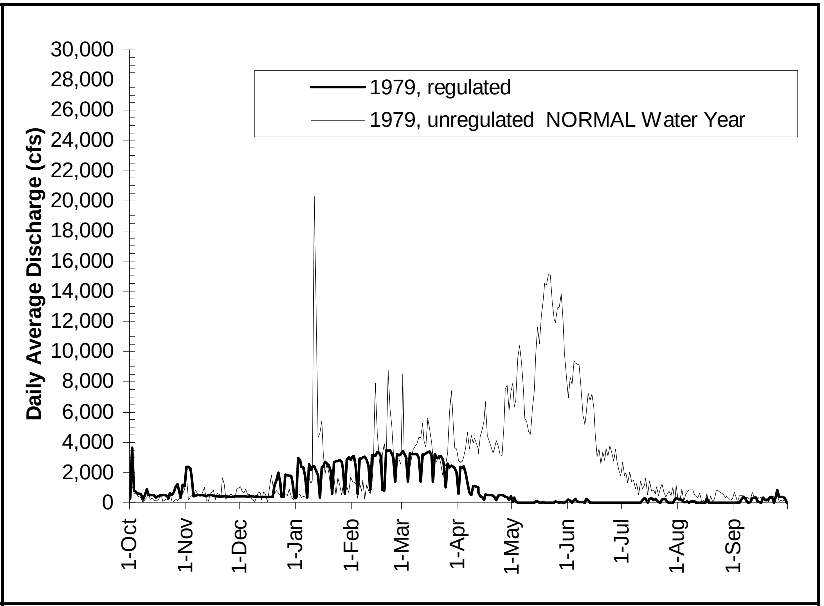
1-Sep


Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1978, regulated
1978, unregulated EX WET Water Year


Daily Average Discharge (cfs)
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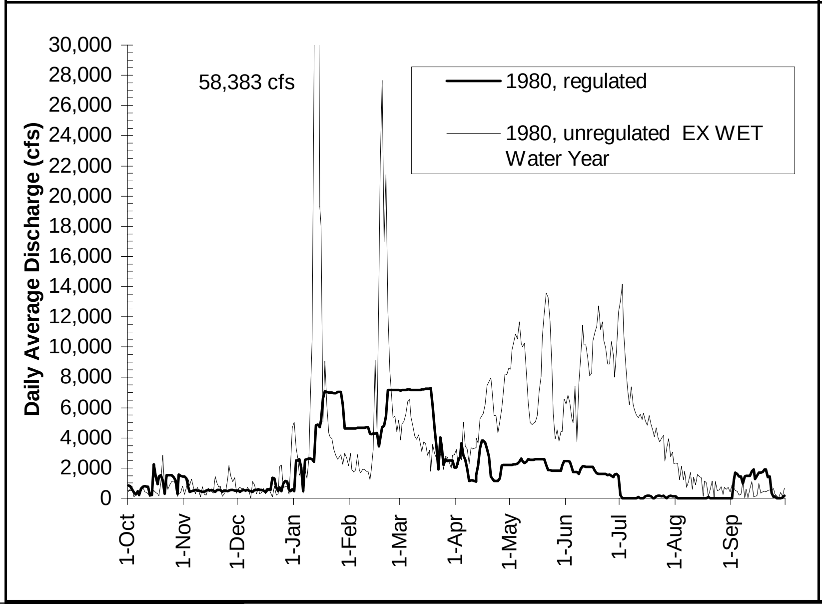
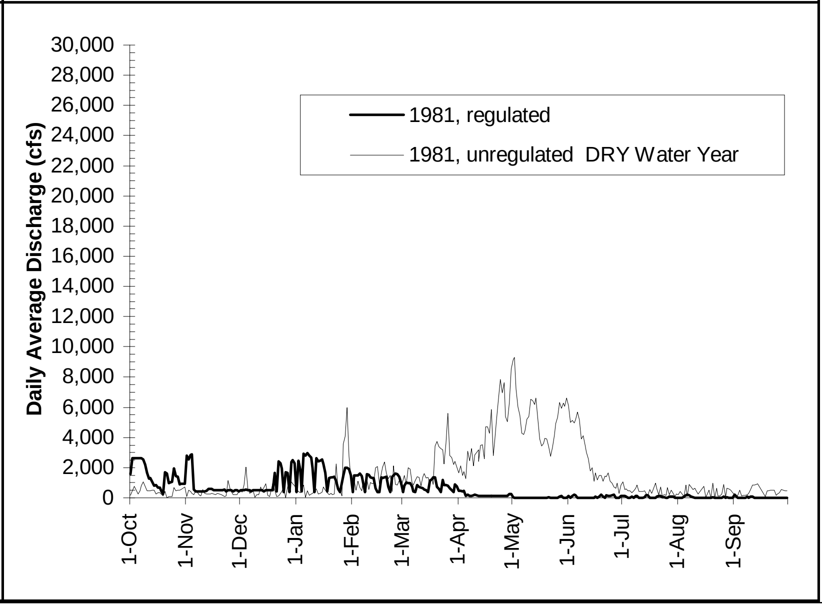
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1979, regulated
1979, unregulated NORMAL Water Year


Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
58,383 cfs
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1980, regulated
1980, unregulated EX WET Water Year


Daily Average Discharge (cfs)
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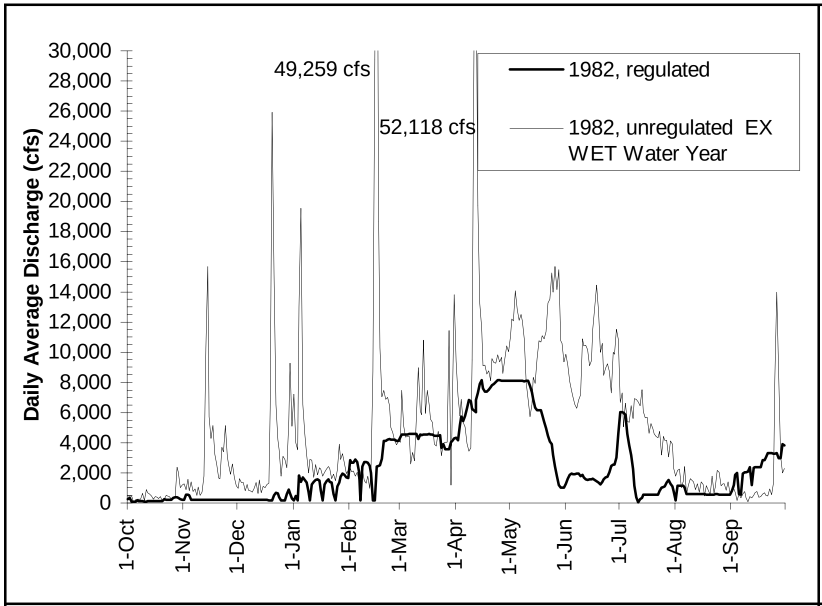
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1981, regulated
1981, unregulated DRY Water Year


Daily Average Discharge (cfs)
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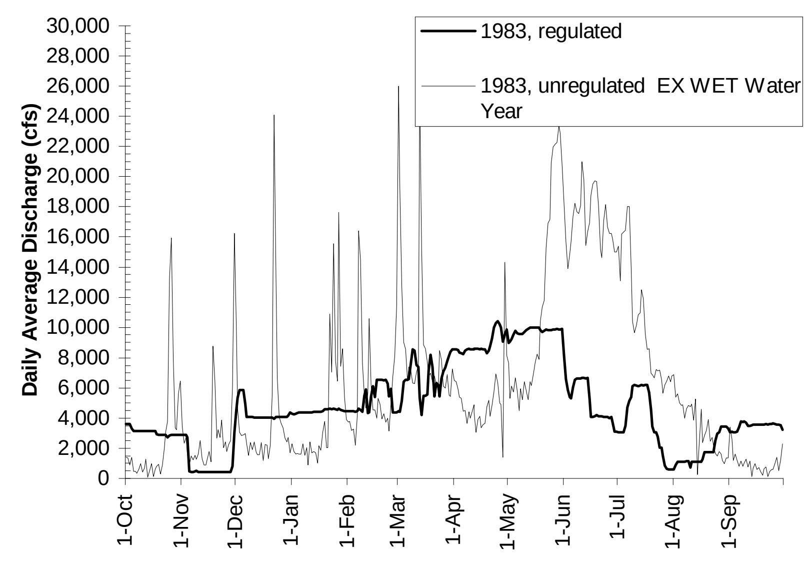
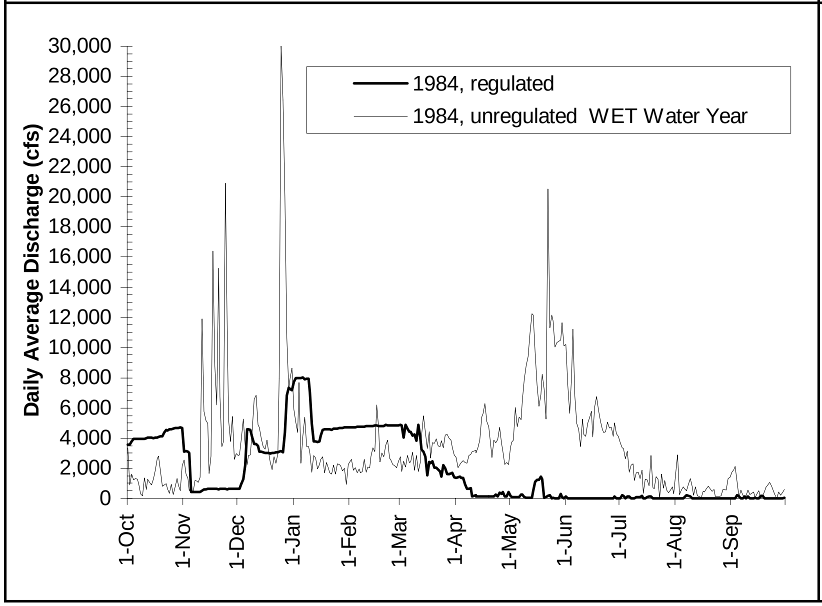
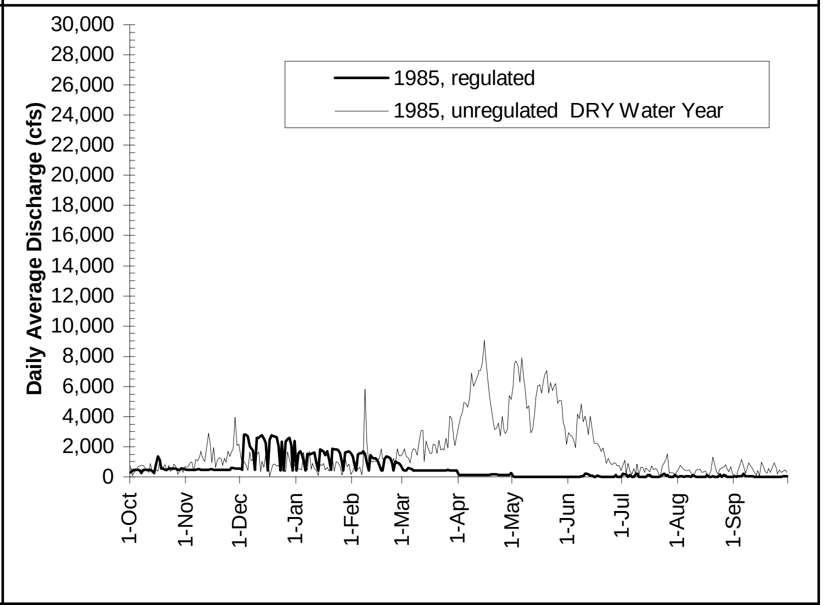
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
49,259 cfs
52,118 cfs
1982, regulated
1982, unregulated EX WET Water Year
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1983, regulated
1983, unregulated EX WET Water Year
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1984, regulated
1984, unregulated WET Water Year
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


Daily Average Discharge (cfs)
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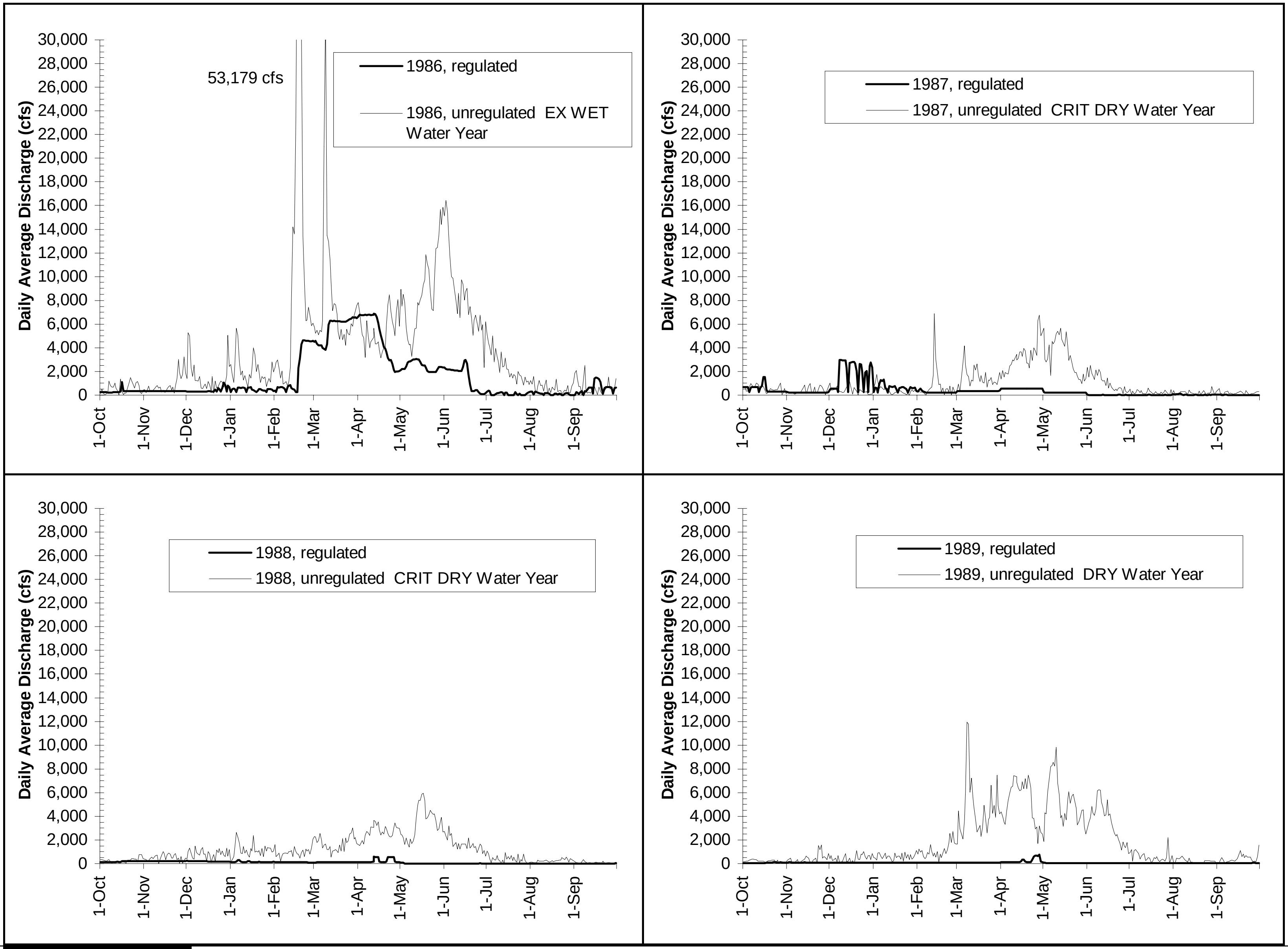
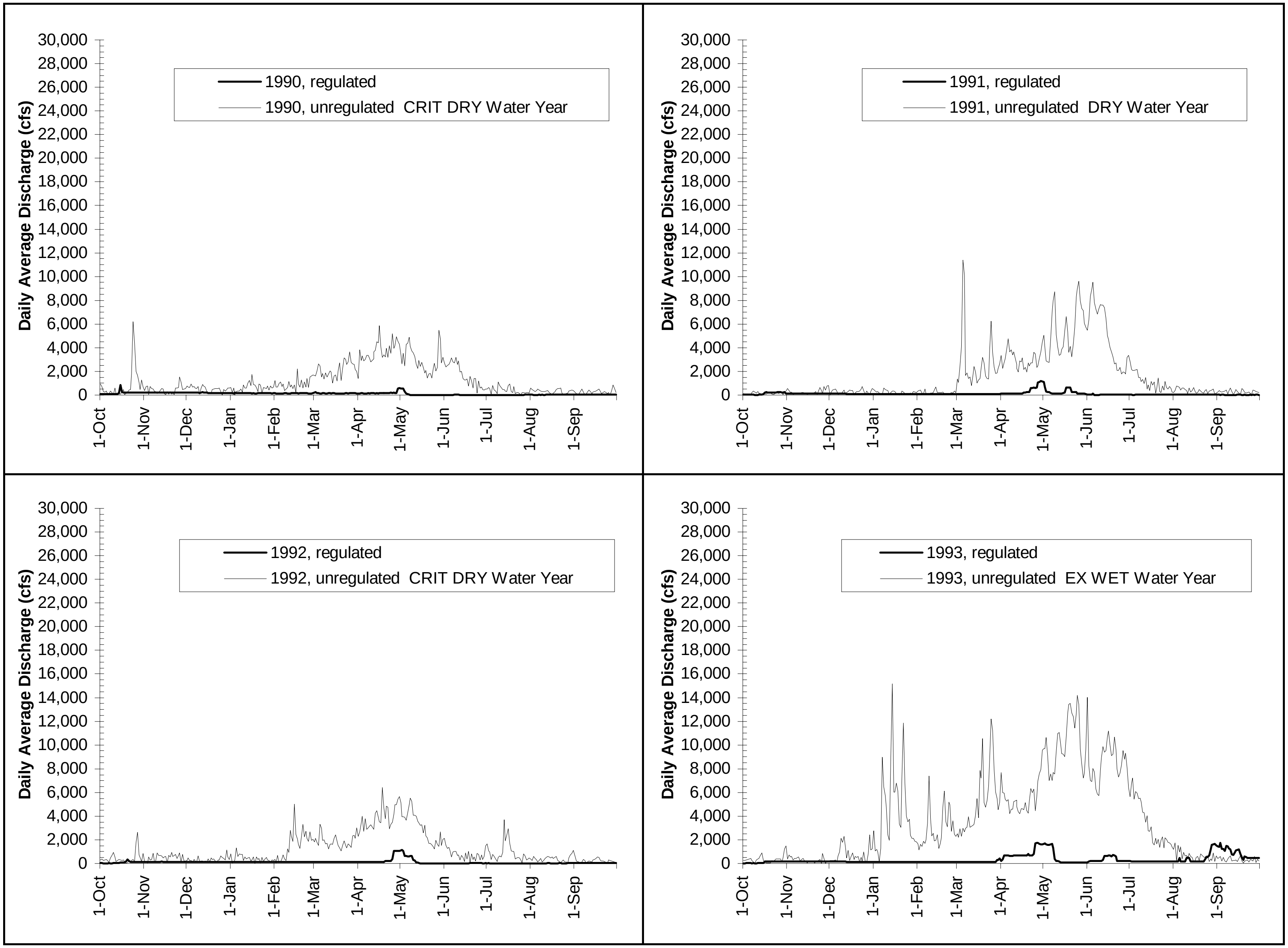
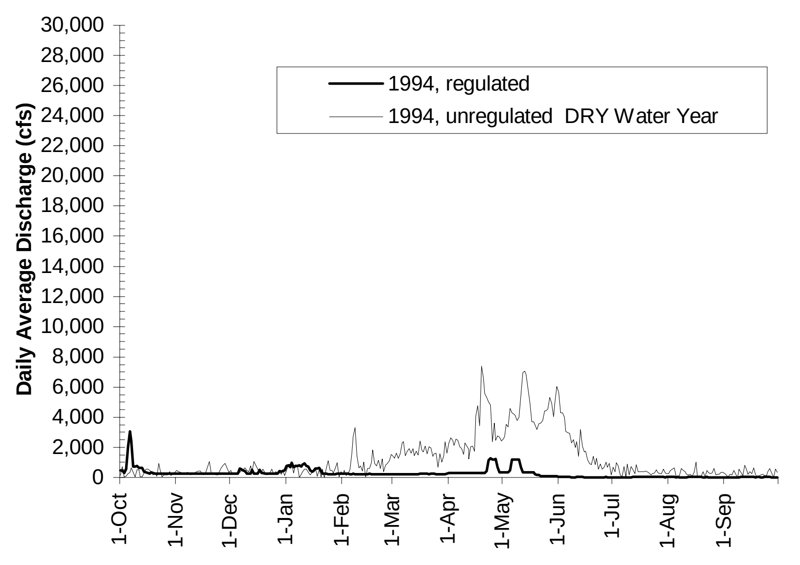
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1985, regulated
1985, unregulated DRY Water Year
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep


30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Daily Average Discharge (cfs)
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
53,179 cfs
1986, regulated
1986, unregulated EX WET Water Year
1987, regulated
1987, unregulated CRIT DRY Water Year
1988, regulated
1988, unregulated CRIT DRY Water Year
1989, regulated
1989, unregulated DRY Water Year


30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Daily Average Discharge (cfs)
1990, regulated
1990, unregulated CRIT DRY Water Year
1991, regulated
1991, unregulated DRY Water Year
1992, regulated
1992, unregulated CRIT DRY Water Year
1993, regulated
1993, unregulated EX WET Water Year
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep



1994, regulated
1994, unregulated DRY Water Year
Daily Average Discharge (cfs)
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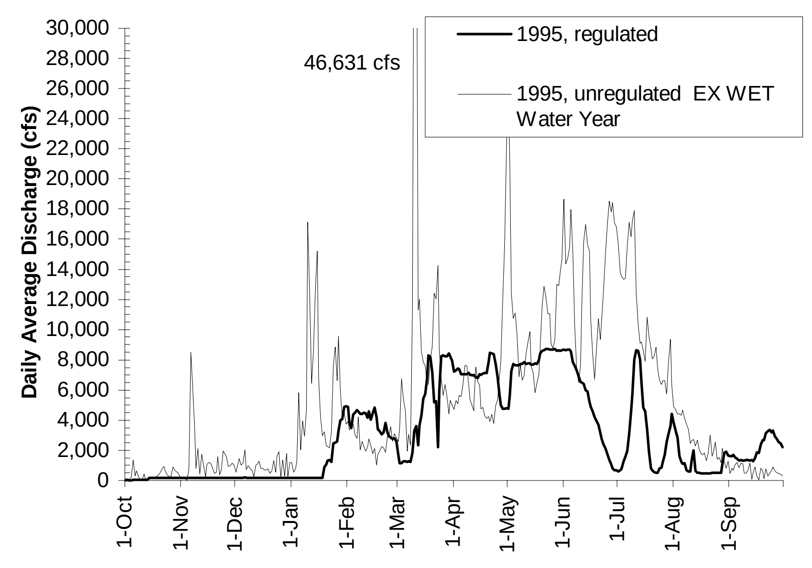
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep



46,631 cfs
1995, regulated
1995, unregulated EX WET Water Year
Daily Average Discharge (cfs)
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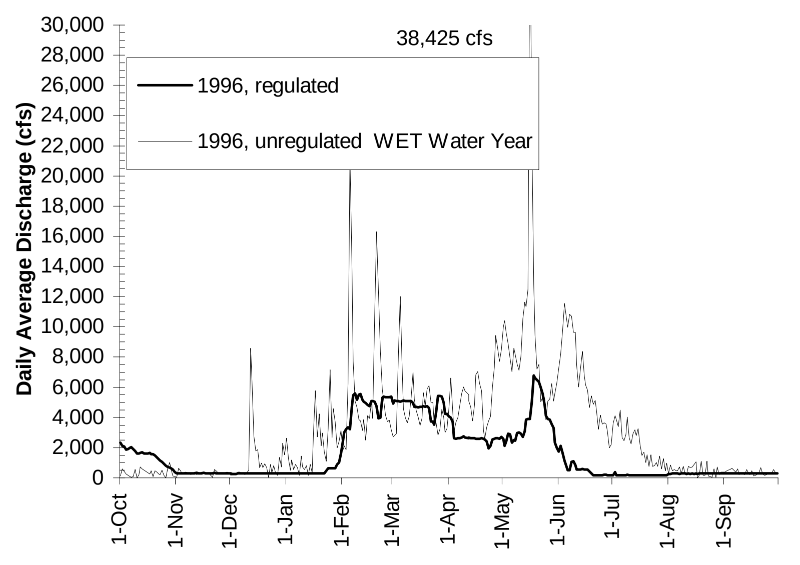
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep



38,425 cfs
1996, regulated
1996, unregulated WET Water Year
Daily Average Discharge (cfs)
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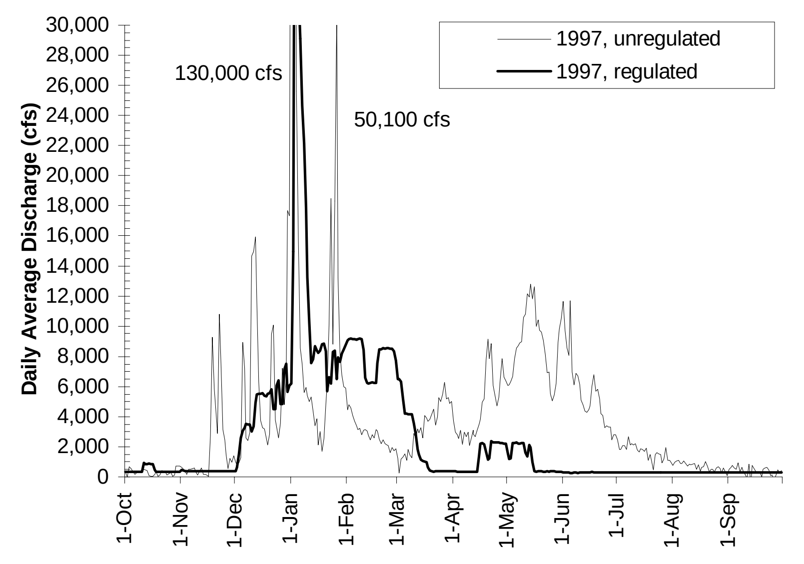
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep



130,000 cfs
50,100 cfs
1997, unregulated
1997, regulated
Daily Average Discharge (cfs)
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep

APPENDIX B

TUOLUMNE RIVER SERIES LISTS, SPECIES LISTS, AND RIPARIAN INVENTORY MAP

VEGETATION SERIES	NATURAL DIVERSITY DATA BASE/HOLLAND TYPE	THE NATURE CONSERVANCY HABITAT STATUS INDEX	"ASSOCIATED" SPECIES OBSERVED
1) Arroyo willow series	Southern cottonwood-willow riparian forest (61330 *in part*)	G3 S3	*Salix lasiolepis*
	Great Valley cottonwood riparian forest (61410 *in part*)	G3 S2.1	*Cephalanthus occidentalis*
	Great Valley mixed riparian forest (61420 *in part*)	G2 S2.1	*Populus fremontii*
	Southern willow scrub (63320 *in part*)	G3 S3.2	*Rubus discolor*
			Sambucus mexicana
2) Black willow series	Southern cottonwood-willow riparian forest (61330 *in part*)	G3 S3	*Salix gooddingii*
	Great Valley cottonwood riparian forest (61410 *in part*)	G3 S2.1	*Alnus rhombifolia*
	Great Valley mixed riparian forest (61420 *in part*)	G2 S2.1	*Ailanthus altissima*
	Southern willow scrub (63320 *in part*)	G3 S3.2	*Arundo donax*
			Cephalanthus occidentalis
			Fraxinus latifolia
			Populus fremontii
			Quercus lobata
			Rubus discolor
			Salix exigua
			Salix lasiolepis
			Salix laevigata
			Salix lucida ssp. lasiandra
			Salix melanopsis
3) Blue elderberry series	Elderberry savanna (63430)	G2 S2.1	*Sambucus mexicana*
	Mexican elderberry series		*Ailanthus altissima*
			Fraxinus latifolia
			Populus fremontii
			Quercus lobata
			Rubus discolor
			Salix exigua
			Vitis californica
4) Blue oak series	Blue oak woodland (71140)	G3 S3.2	*Quercus douglasii*
	Digger pine-oak woodland (71410 *in part*)	G4 S4	*Ailanthus altissima*
			Pinus sabiana
			Quercus lobata
			Quercus wislizenii

VEGETATION SERIES	NATURAL DIVERSITY DATA BASE/HOLLAND TYPE	THE NATURE CONSERVANCY HABITAT STATUS INDEX	"ASSOCIATED" SPECIES OBSERVED
5) Box elder series	Proposed series	N/A	*Acer negundo* var. *californicum*
			Salix exigua
			Salix lasiolepis
6) Buttonbush series	Buttonbush scrub (63430)	G1 S1.1	*Cephalanthus occidentalis*
			Alnus rhombifolia
			Salix exigua
			Salix lucida ssp. lasiandra
			graminoids
7) California buckeye series	Mixed north slope forest (81500)	G4 S4	*Aesculus californica*
			Ficus carica
			Fraxinus dipetala
7) California buckeye series, con't			*Pinus sabiana*
			Quercus lobata
			Quercus douglasii
			Quercus wislizenii
8) California walnut series	California walnut woodland (71210)	G2 S2.1	*Juglans californica*
	Walnut forest (81600)	G1 S1.1	*Fraxinus dipetala*
			Sambucus mexicana
9) Dusky willow series	Proposed series	N/A	*Salix melanopsis*
			Salix exigua
			Salix lasiolepis
			Salix lucida ssp. *lasiandra*
10) Eucalyptus series EXOTIC		N/A	*Eucalyptus camaldulensis*
			Eucalyptus globulus
			Eucalyptus polyanthemos
			Eucalyptus tereticornis
11) Edible fig series EXOTIC	Proposed series	N/A	*Ficus carica*
			Rubus discolor
			Vitis californica

VEGETATION SERIES	NATURAL DIVERSITY DATA BASE/HOLLAND TYPE	THE NATURE CONSERVANCY HABITAT STATUS INDEX	"ASSOCIATED" SPECIES OBSERVED
12) Fremont cottonwood series	Great Valley cottonwood riparian forest (61410 *in part*)	G3 S2.1	*Populus fremontii*
	Great Valley mixed riparian forest (61420 *in part*)	G2 S2.1	*Acer negundo var. californicum*
			Ailanthus altissima
			Arundo donax
			Ficus carica
			Fraxinus latifolia
			Juglans californica
			Morus alba
			Quercus lobata
			Rubus discolor
			Salix exigua
			Salix gooddingii
			Salix lasiolepis
			Salix laevigata
			Salix lucida ssp. *lasiandra*
			Salix melanopsis
			Toxicodendron diversilobum
			Vitis californica
13) Giant reed series EXOTIC		N/A	*Arundo donax*
			Salix exigua
14) Interior live oak series	Interior live oak woodland (71150)	G3 S3.2	*Quercus wislizenii*
	Interior live oak forest (81330)	G4 S4	*Pinus sabiana*
			Quercus douglasii
15) Lamb's quarter's series EXOTIC	Proposed series		*Chenopodium album*

VEGETATION SERIES	NATURAL DIVERSITY DATA BASE/HOLLAND TYPE	THE NATURE CONSERVANCY HABITAT STATUS INDEX	"ASSOCIATED" SPECIES OBSERVED
16) Mixed willow series	Freshwater swamp (52600 *in part*)	G1 S1.1	*Acer negundo* var. *californicum*
	Great Valley cottonwood riparian forest (61410 *in part*)	G3 S3	*Alnus rhombifolia*
	Great Valley mixed riparian forest (61420 *in part*)	G3 S2.1	*Arundo donax*
	Great Valley willow scrub (63410 *in part*)	G2 S2.1	*Ficus carica*
	Southern willow scrub (63320 *in part)*	G3 S3.2	*Fraxinus latifolia*
			Populus fremontii
			Quercus lobata
			Rubus discolor
			Salix babylonica
			Salix exigua
			Salix gooddingii
			Salix lasiolepis
			Salix laevigata
			Salix lucida ssp. *lasiandra*
			Salix melanopsis
			Vitis californica
17) Narrow-leaf willow series	Southern cottonwood-willow riparian forest (61330 *in part*)	G3 S3	*Salix exigua*
	Great Valley cottonwood riparian forest (61410 *in part*)	G3 S2.1	*Alnus rhombifolia*
	Great Valley willow scrub (63410 *in part*)	G3 S3.2	*Arundo donax*
			Cephalanthus occidentalis
			Populus fremontii
			Quercus lobata
			Salix gooddingii
			Salix lasiolepis
			Salix laevigata
			Salix lucida ssp. *lasiandra*
			Salix melanopsis
18) Oregon ash series	Proposed series	N/A	*Fraxinus latifolia*
			Alnus rhombifolia
			Salix exigua

VEGETATION SERIES	NATURAL DIVERSITY DATA BASE/HOLLAND TYPE	THE NATURE CONSERVANCY HABITAT STATUS INDEX	"ASSOCIATED" SPECIES OBSERVED
19) Shining willow series	Freshwater swamp (52600 *in part*)	G1 S1.1	*Salix lucida* ssp. *lasiandra*
	Southern cottonwood-willow riparian forest (61330 *in part*)	G3 S3	*Alnus rhombifolia*
	Great Valley mixed riparian forest (61420 in part)	G3 S2.1	*Fraxinus latifolia*
	Great Valley cottonwood riparian forest (61410 *in part*)	G2 S2.1	*Populus fremontii*
	Great Valley willow scrub (63410 *in part*)	G3 S3.2	*Quercus lobata*
	Pacfic willow series		*Rubus discolor*
			Salix exigua
			Salix gooddingii
			Salix laevigata
			Salix lasiolepis
			Salix melanopsis
			Vitis californica
20) Tree of heaven series EXOTIC	Proposed series	N/A	*Ailanthus altissima*
21) Valley oak series	Great Valley valley oak riparian forest (61430)	G1 S1.1	*Quercus lobata*
	Valley oak woodland (71130)	G2 S2.1	*Aesculus californica*
			Ailanthus altissima
			Morus alba
			Populus fremontii
			Quercus douglasii
			Quercus wislizenii
			Rubus discolor
			Salix melanopsis
			Toxicodendron diversilobum
			Vitis californica
22) White alder series	White alder riparian forest (61510)	G3 S3	*Alnus rhombifolia*
			Cephalanthus occidentalis
			Fraxinus latifolia
			Rubus discolor
			Salix exigua

Nature Conservancy Heritage Program Status Ranks

Global ranks
G1= Fewer than 6 viable occurrences worldwide and/or 2000 acres
G2= 6-20 viable occurrences worldwide and/or 2,000-10,000 acres
G3= 21-100 viable occurrences worldwide and/or 10,000-50,000 acres
G4= Greater than 100 viable occurrences worldwide and/or greater than 50,000 acres
G5= vegetation type is demonstrably secure due to worldwide abundance

State ranks
S1= Fewer than 6 viable occurrences statewide and/or 2000 acres
S2= 6-20 viable occurrences statewide and/or 2,000-10,000 acres
S3= 21-100 viable occurrences statewide and/or 10,000-50,000 acres
S4= Greater than 100 viable occurrences statewide and/or greater than 50,000 acres
S5= vegetation type is demonstrably secure statewide

Threat Ranks
0.1 = Very threatened
0.2 = Threatened
0.3 = No current threats known

References:

Hickman J.C. (Ed.) 1993. *The Jepson Manual Higher Plants of California* .
University of California Press, Berkeley.

Sawyer J.O. and Keeler-Wolf T. 1995. *A Manual of California Vegetation* .
California Native Plant Society.

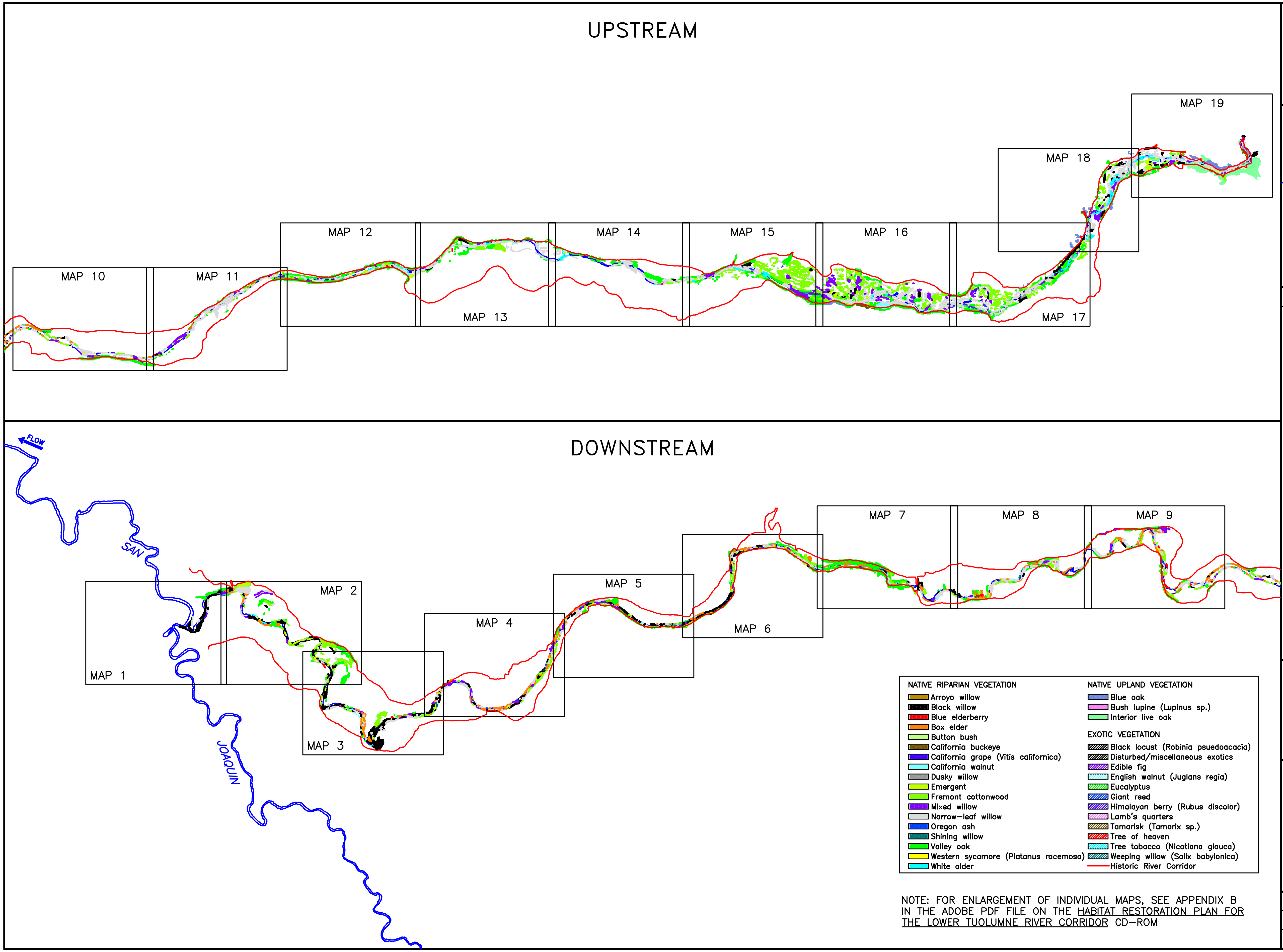
	Scientific Name	Common Name	Locality	Habit	USFWS Hydric Code	SCS Code
1	*Acer negundo var. californicum*	Box Elder	N	Tree	FACW	ACNEC2
2	*Aesculus californica*	California Buckeye	N	Tree		AECA
3	*Ailanthus altissma*	Tree of Heaven	IE	Tree	FACU	AIAL
4	*Alnus rhombifolia*	White Alder	N	Tree	FACW	ALRH2
5	*Eucalyptus camaldulensis*	Red Gum, River Red Gum	IE	Tree		EUCA2
6	*Eucalyptus sp.*	Gum Tree	IE	Tree		EUSP*
7	*Fraxinus latifolia*	Oregon Ash	N	Tree	FACW	FRLA
8	*Fraxinus dipetela*	Ash	N	Tree	FACW	FRDI2
9	*Juglans californica var. californica*	Southern California Walnut	N	Tree	FAC	JUCA
10	*Juglans regia*	Persian or English Walnut	E	Tree	FAC	JURE*
11	*Morus alba*	Fruitless Mulberry	E	Tree		MOAL
12	*Pinus sabiniana*	Grey Pine, Foothill Pine	E	Tree		PISA2
13	*Platanus racemosa*	Western Sycamore	N	Tree		PLRA
14	*Populus fremontii*	Fremont Cottonwood	N	Tree	FACW	POFR2
15	*Quercus douglasii*	Blue Oak	N	Tree		QUDO
16	*Quercus lobata*	Valley Oak, Roble Oak	N	Tree	FAC	QULO
17	*Quercus lobata x douglasii*		N	Tree		QULXD*
18	*Quercus wislizenii var. wislizenii*	Interior Live Oak Tree form	N	Tree		QUWIW
19	*Robinia pseudoacacia*	Black Locust	E	Tree	FAC	ROPS
20	*Salix babylonica*	Weeping Willow	E	Tree	OBL	SABA2
21	*Salix gooddingii*	Goodding s Black Willow	N	Tree	OBL	SAGO
22	*Salix laevigata*	Red Willow	N	Tree	OBL	SALA*
23	*Salix lucida ssp. lasiandra*	Pacific Willow	N	Tree	OBL	SALUL
24	*Tamarix sp.*	Tamarisk	IE	Tree		TASP*
25	*Acer saccharinum*	Silver Maple	E	Tree		ACSA*
26	*Catalpa bignoniodes*	Catalpa	E	Tree		CABI*
27	*Ulmus americana*	American Elm	E	Tree		ULAM*
28	*Cephalanthus occidentalis var. californicus*	Button Bush	N	Shrub	OBL	CEOCC2
29	*Ficus carica*	Edible Fig	IE	Shrub	UPL	FICA
30	*Lupinus sp.*	Bush Lupine	N	Shrub	UPL	LUSP*
31	*Nicotiana glauca*	Tree Tobacco	E	Shrub	FAC	NIGL
32	*Salix exigua*	Narrow-Leaved Willow	IN	Shrub	OBL	SAEX
33	*Salix lasiolepis*	Arroyo Willow	N	Shrub	OBL	SALA6
34	*Salix melanopsis*	Dusky Willow	N	Shrub	OBL	SAME2
35	*Sambucus mexicana*	Blue Elderberry	N	Shrub	FAC	SARA2

	Scientific Name	Common Name	Locality	Habit	USFWS Hydric Code	SCS Code
36	*Toxicodendron diversiloba*	Poison Oak	N	Shrub		TODI
37	*Rhamnus californica ssp. californica*	California Coffeeberry	N	Shrub		RHCACA
38	*Vitis californica*	California Grape	N	Vine	FACW	VICA5
39	*Convolvulus arvensis*	Bindweed, Orchard Morning Glory	IE	Vine		COAR4
40	*Cucurbita palmata*	Coyote Melon	N	Vine		CUPA
41	*Rubus ursinus*	California Blackberry	N	Vine		RUUR
42	*Rubus discolor*	Himalayan Berry	IE	Herb		RUDI2
43	*Rubus leucodermis*	Black Cap Raspberry	N	Herb		RULE
44	*Artemisia douglasiana*	Mugwort	N	Herb	FACW	ARDO3
45	*Baccharis salicifolia*	Mule fat, Seep willow, Water wally	N	Herb	FACW	BASA4
46	*Centaurea solstitialis*	Yellow Star Thistle	IE	Herb		CESO3
47	*Chamaesyce albomarginata*	Rattlesnake Spurge	N	Herb		CHAL11
48	*Chenopodium album*	Pig weed, lambs quarters	IE	Herb	FAC	CHAL7
49	*Datura wrightii*	Jimson Weed	N	Herb		DAWR2
50	*Epilobium sp.*	Willow Herb	N	Herb		EPSP*
51	*Gallium aparine*	Goose Grass	N	Herb	FACU	GAAP2
52	*Gnaphalium sp.*	Everlasting	N	Herb		GNSP*
53	*Helianthus annuus*	Sun Flower	N	Herb	FAC	HEAN3
54	*Mentzelia sp.*	Blazing Star	N	Herb		MESP*
55	*Mimulus guttatus*	Monkey Flower	N	Herb	OBL	MIGU
56	*Phytolacca americana*	Pokeweed, Pokeberry, Pigeon Berry	E	Herb		PHAM4
57	*Plantago sp.*	Plantain	E	Herb	FACW	PLSP*
58	*Polygonum hydropiperoides*	Waterpepper	N	Herb	OBL	POHY2
59	*Rumex crispus*	Curly Dock	E	Herb	FACW	RUCR
60	*Urtica dioica ssp. holosericea*	Hoary Nettle	N	Herb	FACW	URDIH
61	*Xanthium strumarium*	Common Cocklebur	N	Herb	FAC+	XAST
62	*Brassica nigra*	Black Mustard	E	Herb		BRNI
63	*Conium maculatum*	Poison Hemlock	E	Herb		COMA2
64	*Eremocarpus setigerus*	Turkey Mullien	N	Herb		ERSE3
65	*Melilotus alba*	White Sweet Clover	IE	Herb		MEAL2
66	*Melilotus officinalis*	Yellow Sweet Clover	IE	Herb		MEOF
67	*Oenothera elata ssp hirsutissima*	Evening Primrose	N	Herb		OEELH
68	*Osmorhiza brachypoda*	California Sweetcicely	N	Herb		OSBR
69	*Oxalis corniculata*	Oxallis	IE	Herb		OXCO
70	*Plantago major*	Common Plantain	N	Herb		PLMA2

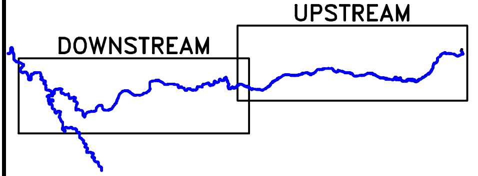
	Scientific Name	Common Name	Locality	Habit	USFWS Hydric Code	SCS Code
71	*Ricinus communis*	Castor Bean	E	Herb		RICO*
72	*Solanum americanum*	Nightshade	N	Herb		SOAM
73	*Verbascum blattaria*	Moth Mullien	IE	Herb		VEBL
74	*Verbascum thapsus*	Mullien	N	Herb		VETH
75	*Vicia americana*	American Vetch	N	Herb	FACU	VIAM
76	*Arundo donax*	Giant Reed	IE	Grass		ARDO4
77	*Avena fatua*	Wild Oat	IE	Grass		AVFA
78	*Bromus sp.*		IE	Grass		BRSP*
79	*Bromus tectorum*	Cheat Grass	E	Grass		BRTE
80	*Cynodon dactylon*	Bermuda Grass	IE	Grass	FAC	CYDA
81	*Echinochloa crus-galli*		IE	Grass		ECCR
82	*Paspalum dilatatum*	Dallis Grass	IE	Grass	FAC	PADI3
83	*Polypogon maritimus*	Beard Grass	IE	Grass	FACW	POMA10
84	*Setaria pumila*		IE	Grass		SEPU8
85	*Adiantum jordanii*	California Maidenhair fern	N	Fern		ADJO
86	*Selaginella hansenii*	Spike Moss	N	Fern		SEHA2
87	*Pentagramma triangularis*	Golden Backed Fern	N	Fern		PETR7
88	*Woodwardia fimbrata*	Giant Chain Fern	N	Fern		WOFI
89	*Cuscuta sp*	Dodder	IN	Parasite		CUSP*
90	*Phorodendron macrophyllum*	Poplar Mistletoe	N	Parasite		PHMA18
91	*Carex sp.*		N	Em Herb		CASP*
92	*Ceratophyllum demersum*	Hornwort, Common coon s tail	N	Em Herb	OBL	CEDE4
93	*Egeria densa*	Brazilian Waterweed	IE	Em Herb	OBL	EGDE
94	*Eichhornia crassipes*	Water Hyacinth	IE	Em Herb	OBL	EICR
95	*Eleocharis sp.*	Spike Rush	N	Em Herb		ELSP*
96	*Elodea canadensis*	Common Waterweed	N	Em Herb	OBL	ELCA7
97	*Juncus effusus*		N	Em Herb	OBL	JUSP*
98	*Lemna minor*	Duckweed	N	Em Herb	OBL	LEMI3
99	*Ludwigia repens*	Water Primrose	N	Em Herb	OBL	LURE2
100	*Myriophyllum aquaticum*	Parrots Feather	IE	Em Herb	OBL	MYAQ2
101	*Myriophyllum hippuroides*	Western Milfoil	N	Em Herb	OBL	MYHI
102	*Potamogeton crispus*	Crispate-Leaved Pondweed	IE	Em Herb	OBL	POCR3
103	*Scirpus acutus var. occidentalis*	Tule	N	Em Herb	OBL	SCACO
104	*Typha latifolia*	Broad-Leaved Cattail	IN	Em Herb	OBL	TYLA
105	*Hydrocotyle verticillata*		IE	Em Herb	OBL	HYVE2
106	*Equisetum arvense*	Common Horsetail	IN	Em Fern	FAC	EQAR

Common names and taxonomy are taken from Hickman, (1993). The scientific name is followed by: (N) for native, (IN) for invasive native, (E) for exotic, and (IE) for invasive exotic. The SCS codes are taken from the soil conservation service index. SCS codes that are followed an asterix are plants for which there was no found code.

TUOLUMNE RIVER
1996–97
RIPARIAN INVENTORY



NOTE: FOR ENLARGEMENT OF INDIVIDUAL MAPS, SEE APPENDIX B IN THE ADOBE PDF FILE ON THE <u>HABITAT RESTORATION PLAN FOR THE LOWER TUOLUMNE RIVER CORRIDOR</u> CD–ROM

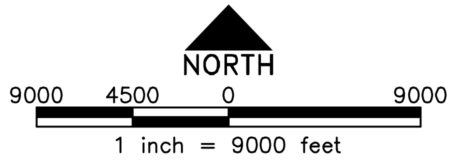


NOTES

A plant series is a vegetation unit defined by a dominant species, a co–dominance between a few species, or, in some cases, a single species. (See Sawyer and Keeler–Wolf, 1995.)

We mapped plant series, small groups of plants that do not form series, and individual plants. For presentation, individual plants of a given species and a series defined by the same species are indicated by the same legend code. Individual or small groups of a plants that do not form series are presented and listed in the legend followed by their scientific name.

1) Most vegetation was field mapped in Sep–Oct 1996 with some areas filled in April 1997.
2) Large off–channel areas (e.g. dredger tailing reach) were mapped by aerial photo interpretation on April 1997 photos.
3) 5/20/91 river channel (620 cfs) and off–channel mining pits were mapped by HJW and EA Engineering from 5/20/91 aerial photos.
4) Hatched areas indicate exotic vegetation.



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